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THE RELATIVE EFFECTIVENESS OF PHOSPHATIC FERTILIZERS

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PHOSPHATE deficiency is widespread in Scottish soils, many of which appear to have high capacities for fixing phosphate in unavailable forms and require frequent applications in order to maintain yields. Modification of the chemical and physical form in which phosphate is applied is one approach to the problem of reducing fixation and increasing the efficiency of phosphatic fertilizers [1], and field and pot experiments have recently been carried out with different phosphates, including granular and powdered forms, to compare their effectiveness in various soils. These experiments form part of a wider investigation of the phosphate relationships of Scottish soils, covering points such as the significance of pedological differences, the interaction of lime and phosphate, and the laboratory assessment of phosphate status. These and other aspects of the subject will be dealt with in future publications, and the treatment of the present results is therefore restricted largely to the relative effectiveness of the different phosphates as measured by their immediate and residual effects on the yield and composition of crop.

Experimental

Soils.—In the choice of field centres a combination of representative pedological type, phosphate-deficient soil, and responsive crop was aimed at and the emphasis laid on granitic soils because previous experiments [2] and practical experience indicate that they present a major problem. Soil types were chosen on the basis of soil-survey information [3] in consultation with members of the soil-survey department of the Institute, and field experiments have been carried out at 17 centres on soils of various geological origins including, as indicated in the Tables, granitic, basic igneous, andalusite schist, Old Red Sandstone, and mixed drifts. In texture, they ranged from loamy sands to loams with clay-contents varying from 11 per cent. at centre 1 to 22 per cent. at centre 4. The approximate contents of organic matter varied from 7 per cent. at centre 14 to 17 per cent. at centre 17, but were mostly between 11 and 14 per cent. The soils were all acid and, except for centre 14 (pH 4·7) and centre 13 (pH 6·1), the pH values fell between 5·2 and 5·8.

Phosphates.—The materials tested together with symbols and analyses are given in Table 1. The high-temperature phosphates 'C' and 'F', Nos. 2 and 3, were experimental products, 'F' being essentially the same as the silicophosphate, No. 4, described by Crowther and Lea [4]. Phosphate 'C' came from an earlier experimental batch prepared with less soda and having a lower citric solubility. The super-lime and serpentine-super represent superphosphate reverted with lime and serpentine respectively [1, 5], No. 7 being an experimental local product which did not fully revert. Super-dolomite, No. 6, was also prepared locally

TABLE 1. *Reference Symbols and Analyses of Phosphates*

Symbol	*Material*	*Total P_2O_5%*	*P_2O_5% soluble in 2% citric acid*	*P_2O_5% water-soluble*	*Citric solubility %*	*Mechanical composition, %*			
						> 1 mm.	*< 1 mm. > 0·5 mm.*	*< 0·5 mm. > 100-mesh*	*< 100-mesh*
1 S	Superphosphate	19·9	..	18·9	..	..	..	..	..
2 C	Experimental high-temperature phosphate 'C'	31·4	24·6	0	78	1	1	13	85
3 F	Experimental high-temperature phosphate 'F'	34·5	31·9	0	93	0·5	0·5	3	96
4 SP	Silicophosphate (P563)*	33·2	30·1	0	91	1	3	31	65
5 Meta	Calcium metaphosphate	70·0	10·6	1·6	15	4	7	21	69
6 SD	Super-dolomite	16·2	13·6	0·5	84	..	..	..	..
7 SS	Serpentine-super	15·8	13·9	6·7	88	..	..	..	..
8 SS	Serpentine-super (P569)	13·9	12·7	1·1	91	..	..	..	..
9 SL	Super-lime (P570)	16·5	14·2	0·6	86	..	..	..	..
10 DCP	Dicalcium phosphate (P560)	39·8	39·8	0	100	..	..	..	..
11 TS	Ordinary triple-superphosphate	47·8	..	38·9	..	20	17	38	25
12 GTS	Granular triple-superphosphate	48·2	..	40·6	..	80	17	2	1
13 SBF	Steamed bone-flour	34·6	25·5	0	74	0	4	35	61
14 SBF	Steamed bone-flour, 100-mesh	34·7	27·2	0	78	0	0	2	98
15 GSB	Granular steamed bones	32·1	21·8	0	68	53	20	17	10
16 GSB	Granular steamed bones	30·7	19·3	0	63	19	18	37	26
17 SBM	English steamed bone-meal	25·8	15·4	0	60	42	18	26	14
18 GC	Ground coprolite	14·7	4·7	0	32	..	..	..	90
19 MP	Ground mineral phosphate	33·1	9·6	0	29	0	1	42	57
20 GMP	Gafsa mineral phosphate	27·8	10·5	0	38	0	0	7	93
21 GMP	Gafsa mineral phosphate (P529)	26·2	11·4	0	44	0	1	9	90
22 MMP	Morocco mineral phosphate (P530)	31·2	10·1	0	33	1	2	20	77
23 CMP	Curaçao mineral phosphate (P531)	34·4	10·2	0	30	2	3	18	77
24 Sem	Semsol (P564)	26·5	14·5	8·7	55	16	9	35	40

* The brackets contain the Rothamsted reference numbers of the materials—see acknowledgement.

using dolomite as reverting agent [6]. The granular steamed bones, Nos. 15 and 16, represent granular steamed bone-flour, and phosphate No. 17 is described commercially as 'steamed bone-meal in an improved mechanical condition'. The ground coprolite, No. 18, came from Norfolk and the Semsol, No. 24, was prepared in Northern Ireland where it is a popular form.

Field technique.—The experiments all consisted of randomized blocks, the treatments being randomized in each of four blocks at centres (1) to (5), and in each of the three blocks at the remainder.

In each case suitable basal dressings of nitrogen and potash were applied to the whole area each year the experiment was in progress, but no dressing of phosphate other than the initial one was applied in any of the experiments. The plots in most instances were 1/100 acre in area, and the first crop was either potatoes, turnips, or swedes. With potatoes, the phosphates were broadcast after the initial ridging and, with roots, broadcast on the flat before ridging. The phosphates and the basal dressings were applied at seed-time, but where the experiments included lime-treatments the lime was applied as early as possible, generally about three months beforehand, and in an amount sufficient to give a final pH of about 6·2.

Superphosphate, either ordinary or triple, has been used as the standard for comparison throughout, and in all but two of the experiments was applied at two rates at least to give the form of the response-curve and an indication of the sensitivity of the comparison. In several of the experiments the other phosphates were also applied at two rates to give direct comparisons at two levels.

Pot technique.—The comparisons were carried out in Mitscherlich pots [7], using a mixture of 1 pt. by volume of soil (passing a ¼-in. sieve) to 2 pts. of washed sand, incremental additions of phosphate, standard Mitscherlich dressings of N, K, Ca, and Mg, and oats as indicator plants. The crop was grown to maturity and harvested to give the yield of oven-dry grain and straw. The soils used were spade samples taken from field-experiment areas, and each treatment was carried out in at least duplicate and generally in triplicate. Comparisons were also carried out in sand without added soil.

Results

Full details of individual field experiments are given in Tables 2 to 9. The results for the main groups of phosphates are distributed as follows: high-temperature phosphates—Tables 2, 3, 8, 9; reverted phosphates and dicalcium phosphate—Tables 4, 8, 9; bone fertilizers and granular forms—Tables 5, 6, 7; mineral phosphates—Tables 4, 5, 8, 9; Semsol—Tables 8, 9; calcium metaphosphate—Table 3. The Tables (pp. 9–13) are self-explanatory and detailed comment on individual experiments and materials is withheld to economize in space.

The results of the pot comparisons are given in Tables 10 to 12, which represent separate sets of tests carried out over a period of three years. They present a similar general picture of the relative effectiveness of the different phosphates and their relationship to field experiments is

commented on in the ensuing discussion. In another series of tests, the results of which are not included in the Tables, no appreciable difference was found between Gafsa, Morocco, and Curaçao mineral phosphates (Nos. 21, 22, and 23) in a sand–granitic soil medium.

Discussion

The present experiments were carried out primarily to investigate the effectiveness of the high-temperature phosphates, dicalcium phosphate, reverted phosphates, metaphosphate, and phosphates in granular form, about which little or no information was available under Scottish conditions. The effectiveness of common forms, such as mineral phosphates, basic slag, and bone fertilizers, has frequently been tested in the past [8, 9], and mineral phosphates were included in the present series largely to provide an extreme contrast to superphosphate and facilitate the interpretation of data for materials of intermediate solubilities.

The main feature of the results is the absence of major differences in the over-all effectiveness of phosphates other than mineral phosphates, Semsol, and metaphosphate. It is immediately apparent that for practical purposes the other forms are equally effective. The effectiveness of the mineral phosphates on turnips and swedes is variable. It would appear that they can frequently be expected to equal superphosphate but are liable to be relatively ineffective. This variable behaviour does not appear to be a characteristic of one particular material or a function of any common soil property. It is well known that their usefulness is confined to acid soils and that, as is well illustrated by the results in Table 9, they are relatively ineffective on potatoes; it is, however, noteworthy that whereas Semsol and Gafsa phosphate show very similar results on turnips, there seems to be a slight trend in favour of the former on potatoes. There does not appear to be any advantage in the use either of Semsol or of composite dressings of superphosphate and mineral phosphate. The availability of metaphosphate is presumably governed by the rate of hydrolysis into the ortho form, and the trend of the results in conjunction with its low citric-solubility suggests that its general behaviour may be expected to resemble that of mineral phosphates.

The citric-acid test is undoubtedly valuable because materials of low citric-solubility, such as the mineral phosphates, are definitely inferior to citric-soluble forms such as silicophosphate and dicalcium phosphate, which are very effective on potatoes and show up to equal or even slightly greater advantage where lime is applied (Tables 8 and 9). It would appear, however, that too much emphasis has been placed on water-solubility as a criterion of manurial value but, on the other hand, there is no general indication that water-insoluble phosphates of high citric-solubility are consistently better than superphosphate, which is not easily surpassed. Also, although there is sometimes a tendency for lack of effect on yield to be compensated to some extent by increased P_2O_5-uptake, as in phosphate 'C', Table 2, there is seldom any marked difference in P_2O_5-uptake from phosphates with similar yield-effects.

Granulation has been suggested as a means of increasing the efficiency of soluble phosphates by reducing the rate of fixation and providing

phosphate-rich pockets in the soil, but there is no significant difference in the effectiveness of granular and powdered triple-superphosphate in the present experiments. The maximum size of granule, however, was only about $\frac{3}{16}$ in. and the possibility remains that larger granules might be more effective. Granulation is generally associated with water-soluble forms and it is noteworthy, therefore, that the granular steamed bones tend, if anything, to be slightly superior to ordinary steamed bone-flour. This indicates that some water-insoluble phosphates of this type might probably be granulated without any adverse effect on their manurial value. Since granular products are very convenient to handle and distribute, this possibility is of practical interest.

The only appreciable residual effects obtained were those shown in Tables 2 and 7, and it will be seen that there are no significant differences between forms. The results in Table 7 are of interest in that centres 12 and 13 represent well-drained and poorly-drained parts, respectively, of a field. Appreciable residual effects occurred only in the poorly-drained part, but the yield-level was higher in the well-drained area. This would appear to be a further example of the contrasts noted by Glentworth [10] in the phosphate relationships of corresponding well-drained and poorly-drained soils. It is noteworthy that, at the rates used, water-insoluble forms such as silicophosphate, dicalcium phosphate, and steamed bone-flour showed no advantage in residual effects. If, as has frequently been suggested, such forms are less rapidly fixed they might be expected, provided they are intrinsically available, to be superior in this respect. The fact that they are not is compatible with the evidence obtained by Williams and Stewart [2] that basic slag was rapidly fixed in an acid granitic soil. It would appear that the residual effects, even of the heavier dressings, are generally small or negligible irrespective of the form used, and the nature of the response-curves suggests that, as a rule, there is little further increase in yield to be obtained from dressings higher than about 80–100 lb. P_2O_5 per acre, even with sensitive crops like roots. Heavier applications may be expected to affect the P_2O_5-uptake and quality of the crop, as happens in the case of the 500-lb. P_2O_5 super dressing in Table 2, but, even so, the use of dressings considerably in excess of about 1 cwt. P_2O_5 per acre would appear to be generally uneconomical. Frequent applications in accordance with the responsiveness of each crop seem preferable to a single heavy application during the rotation.

There is no indication of any appreciable variation in the relative effectiveness of the different phosphates in soils of different geological origin. The mineral phosphates are the only forms showing major variations, and their relative effectiveness in acid soils appears to depend more on the crop than the type of soil. Pedological differences seem more likely to be reflected in the level of yield and in the general response to, uptake of, and need for phosphate. Some indication has already been obtained that a satisfactory phosphate status is more easily maintained in soils derived from Old Red Sandstone than in soils of granitic origin. These and other aspects of the phosphate relationships of different soils are being further investigated.

The results of the pot trials indicate that they can provide a useful indication of the probable field effectiveness of a given form of phosphate, especially when the general relationship between field and pot results has been established. The pot tests are more sensitive in that they invariably exaggerate phosphate deficiencies and also tend to show greater differences between forms. These differences tend to be more pronounced in sand alone than in soil–sand media, as may be seen from Tables 11 and 12. This is not surprising because, apart from the oat-seed, there is no other source of phosphate present and the sand would not be expected to fix phosphate in unavailable form to any appreciable extent. The sand also shows a normal behaviour in that the apparent inferiority of comparatively available forms, such as super-dolomite, Table 11, disappears in the highest rate of addition when the maximum yield is approached. This does not apply to the relatively insoluble coprolite, Table 11, but is apparent in the following figures which show the relative yields from superphosphate, metaphosphate, and phosphates 'C' and 'F' in sand, the maximum yield from superphosphate being put at 100:

P_2O_5-rate	*Super*	*Metaphosphate*	*'C'*	*'F'*
0·15	88	64	82	80
0·50	100	111	107	96
1·00	100	104	98	99

In soil–sand media, however, the variations between forms persist and are frequently more pronounced in the higher P_2O_5-rates (Tables 10, 11, and 12). This contrast between the sand and the soil–sand media is probably largely attributable to the effect of the phosphate present in the soil and to fixation of added phosphate by the soil. The phosphate supplied by the soil will tend to obscure differences between forms, the effect being greater with low P_2O_5-rates, since the soil phosphate then constitutes a higher proportion of the total present. Fixation should affect all forms of added phosphate, but may be expected to affect the more soluble forms to a greater extent than the less soluble ones and to affect comparisons to a greater extent the lower the rate of P_2O_5-addition. There is no doubt that fixation in unavailable forms occurs in pot experiments of this type and, as has already been noted [2], the growth-curves frequently tend to assume a sigmoid form. The period of about ten days between planting and germination during which the pots are kept covered in a moist condition may well be critical in this connexion. The intervention of these factors appears sufficient to account for the rather different relative behaviour of phosphates in soil–sand and sand media. The same factors should affect the comparison between pot results for soil–sand media and field results, and they probably contribute to the somewhat lower sensitivity of the field trials. But in addition to the fact that the crops are different in the present instances, the artificial nature of the pot conditions introduces many other factors, such as moisture and microbiological relationships, the influence of which cannot be readily assessed. Of the pot comparisons, those at low rates in

soil–sand media are in closest agreement with the field results, and it appears safe to predict that a phosphate effective on oats in the pots will be effective on swedes, turnips, and potatoes in the field, but it does not always follow that a form relatively less effective in the pots will be equally so in the field.

Calcium glycerophosphate was found to compare favourably with superphosphate in pot tests with a sand–granitic soil medium. This high availability is in agreement with the results of Spencer and Stewart [11], who also found organic forms of this type to have high penetrative powers in soils. Pinck, Sherman, and Allison [12], on the other hand, found that sodium glycerophosphate was rapidly fixed. The possibility remains, however, that such organic forms might find a practical application if they could be produced economically.

The immediate effects reported in the present paper were all measured with either turnips, swedes, or potatoes, but Stewart and Reith [13] found superphosphate, serpentine-super, and basic slag to be equally effective in re-seeding experiments, and have since found, in experiments on fertilizer placement, the results of which will be published later, that there is no appreciable difference in the effects of silicophosphate and superphosphate on the yield of oats. The great majority of Scottish soils are acid, even where a reasonable liming policy is followed, and under these conditions there is little doubt that, apart from the possible lower effectiveness of mineral phosphates, Semsol, and metaphosphate, especially on potatoes, the form used is unimportant compared with the widespread need for and response to phosphate. All the present experiments were of a short-term character but, disregarding mineral phosphate and Semsol, there is no suggestion that continued rational use of any one form over a long period would result in markedly superior cumulative effects. In addition, modification of the nature of the form used does not appear to be a promising approach to the problem of increasing the efficiency of applied phosphate. Material improvements in this respect seem more likely to result from modification of the method of application by suitable placement of the phosphate [1, 13]. In Scottish soils at least, any attempt at rapid accumulation of reserves of phosphate intended to last for years seems fundamentally unsound and uneconomical and, in the present state of knowledge, frequent application of phosphate in accordance with the responsiveness of individual crops, coupled with suitable placement and adequate liming, is undoubtedly the soundest practice.

Summary

1. The relative effectiveness of a series of phosphatic fertilizers, including powdered and granular forms, has been investigated by field and pot experiments on acid soils of different geological origins. The experiments form part of a wider long-term investigation of the phosphate relationships of Scottish soils.

2. No marked or consistent difference has been found in the effectiveness of phosphates other than mineral phosphates, calcium metaphosphate, and Semsol. The metaphosphate and Semsol gave results similar to those of mineral phosphates which were frequently effective on turnips

and swedes but not on potatoes. The citric-solubility test provides a useful distinction in the latter connexion, but too much emphasis appears to have been placed on water-solubility as a criterion of manurial value.

3. Granulation did not alter the effectiveness of triple-superphosphate and no major difference was found between granular steamed bones and steamed bone-flour.

4. There is no indication of any appreciable variation in the relative effectiveness of different phosphates in soils of various geological origins, and pedological differences seem more likely to be reflected in the level of yield and in the response to, uptake of, and need for phosphate.

5. Even with responsive crops on very deficient acid soils there is, as a rule, little or no further increase in yield obtained with dressings higher than about 80–100 lb. P_2O_5 per acre, and applications considerably in excess of this amount would appear to be uneconomical because the residual effects are generally very small irrespective of the form used. Frequent application of phosphate in accordance with the responsiveness of individual crops, coupled with suitable placement and adequate liming, is undoubtedly the soundest practice.

6. Pot experiments of the Mitscherlich type invariably exaggerate a phosphate deficiency and tend to show greater differences between forms, but the results obtained in soil–sand media with a P_2O_5-addition of 0·1–0·2 gm. per pot give a useful indication of field effectiveness.

7. Material increases in the efficiency of applied phosphate seem more likely to be obtained by suitable placement than by modifying the form used.

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TABLE 2. *Field Comparisons of Super and High-temperature Phosphates at Centre 1—Granitic**

Phosphate	P_2O_5-rate† lb.	1st year—potatoes			2nd year—swedes			3rd year—swedes		
		Tons†	P_2O_5 % DM	P_2O_5-uptake lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.
..	0	13·9	0·44	29	17·3	0·78	20	10·4	0·48	7
1 S	140	14·6	0·56	38	21·2	0·85	26	12·0	0·63	10
2 C	140	13·6	0·67	35	23·3	0·58	19	13·0	0·49	8
3 F	140	15·6	0·60	42	22·2	0·64	20	12·5	0·49	7
1 S	500	15·2	0·56	46	24·9	0·86	32	16·1	0·71	15

* In all tables, 'granitic', 'basic', &c., indicate the predominant character of the parent drift and the symbol 'DM' indicates dry matter from produce dried at 80° C.

† In Tables 2–9, the P_2O_5-rates, the yields (fresh tubers and roots), and the P_2O_5-uptakes are on an acre basis.

TABLE 3. *Field Comparisons of Super, High-temperature Phosphates, and Metaphosphate at Centres 2—Granitic, and 3—Basic*

Phosphate	P_2O_5-rate lb.	Turnips (tons)	
		Centre 2	Centre 3
..	0	15·6	11·0
1 S	112	20·4	18·5
2 C	112	20·2	17·8
3 F	112	19·7	18·2
5 Meta	112	19·2	14·5

TABLE 4. *Field Comparisons of Super, Super-dolomite, and Coprolite on Turnips at Centres 4—Basic, and 5—Granitic*

Phosphate	P_2O_5-rate lb.	Centre 4			Centre 5		
		Tons	P_2O_5 % DM	P_2O_5-uptake lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.
..	0	16·6	0·46	14	15·1	1·06	29
1 S	40	21·2	0·52	20	19·4	1·31	46
6 SD	40	21·6	0·68	26	18·4	1·25	41
18 GC	40	21·2	0·73	28	16·6	1·06	32
1 S	100	26·5	0·67	32	19·8	1·34	48
6 SD	100	25·2	0·67	31	20·4	1·37	50
18 GC	100	23·6	0·73	31	16·8	1·27	38

TABLE 5. *Field Comparisons of Triple-super, Steamed Bone-flour, Granular Steamed Bones, and Mineral Phosphate at Centres 6 and 7—Granitic, and 8—Basic*

		Centre 6			*Centre 7*	*Centre 8*
Phosphate	P_2O_5-*rate lb.*	*Turnips (tons)*	P_2O_5 *% DM*	P_2O_5-*uptake lb.*	*Swedes (tons)*	*Turnips (tons)*
..	0	16·6	0·72	22	19·4	8·4
11 TS	40	15·6	0·63	18	21·5	13·6
13 SBF	40	17·7	0·68	22	21·5	13·2
15 GSB	40	19·9	0·69	25	21·3	14·6
11 TS	80	20·6	0·57	22	21·5	14·7
13 SBF	80	20·5	0·61	23	23·3	14·4
15 GSB	80	21·8	1·09	43	21·4	15·0
19 MP	80	16·8	0·38	12	..	..
½ 19 MP + ½ 11 TS	80	18·2	0·49	16	23·1	14·4
½ 13 SBF + ½ 11 TS	80	..	..	..	21·9	15·4
	S.E.	±1·17			±0·69	±1·48

TABLE 6. *Field Comparisons of Ordinary and Granular Triple-super, Ordinary, and 100-mesh Steamed Bone-flour, Granular Steamed Bones, and Steamed Bone-meal at Centres 10 and 11—Granitic*

		Centre 10	*Centre 11*
Phosphate	P_2O_5-*rate lb.*	*Turnips (tons)*	*Swedes (tons)*
..	0	1·3	26·2
11 TS	20	5·4	25·3
11 TS	40	11·1	30·4
12 GTS	40	10·8	30·3
13 SBF	40	7·7	27·5
14 SBF	40	8·4	29·7
16 GSB	40	11·4	30·4
17 SBM	40	8·4	28·4
11 TS	100	14·8	30·9
	S.E.	±1·57	±1·50

TABLE 7. *Field Comparisons of Ordinary and Granular Triple-super, Steamed Bone-flour, and Granular Steamed Bones at Centres 12 and 13—Mixed Drift*

		Centre 12				Centre 13			
		1st year—potatoes				1st year—potatoes			
Phosphate	P_2O_5-rate lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.	2nd year—swedes (tons)	Tons	P_2O_5 % DM	P_2O_5-uptake lb.	2nd year—swedes (tons)
..	0	8·9	0·59	20	26·3	9·7	0·57	22	16·6
11 TS	40	9·6	0·60	23	25·8	11·3	0·54	23	20·5
12 GTS	40	9·4	0·55	19	25·8	10·7	0·52	22	20·9
13 SBF	40	10·5	0·61	23	27·0	9·7	0·48	19	17·4
16 GSB	40	8·7	0·55	18	24·1	10·1	0·53	21	20·0
11 TS	80	9·4	0·60	20	25·9	10·8	0·57	23	23·6
12 GTS	80	10·1	0·60	22	24·5	10·7	0·53	22	19·0
13 SBF	80	9·7	0·55	20	26·4	10·0	0·54	23	21·6
16 GSB	80	8·7	0·65	20	25·1	9·9	0·51	21	22·1
	S.E.	±0·66				±0·33			

TABLE 8. *Field Comparisons of Super, Silicophosphate, Dicalcium Phosphate, Serpentine-super, Gafsa Phosphate, and Semsol on Turnips at Centres 14— Old Red Sandstone, 15—Andalusite Schist, and 16—Granitic*

			Centre 14			Centre 15			Centre 16		
	Phosphate	P_2O_5-rate lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.	Tons	P_2O_5 % DM	P_2O_5-uptake lb.
Unlimed	..	0	7·3	0·56	8	6·4	0·38	5	16·7	0·65	18
	1 S	40	10·8	0·63	14	17·7	0·42	14	18·5	0·76	25
	4 SP	40	11·8	0·67	15	17·2	0·45	15	18·2	0·72	22
	10 DCP	40	12·0	0·68	17	16·5	0·43	13	17·6	0·76	22
	8 SS	40	11·7	0·71	17	17·3	0·43	14	17·1	0·78	23
	20 GMP	40	12·1	0·69	16	16·0	0·54	15	16·4	0·76	21
	24 Sem	40	10·8	0·67	14	15·7	0·49	13	16·4	0·76	21
	1 S	80	16·2	0·81	26	20·9	0·59	21	18·3	0·86	27
Limed	..	0	10·0	0·65	12	9·3	0·46	8	15·2	0·77	19
	1 S	40	14·8	0·80	19	17·7	0·44	14	17·4	0·77	22
	4 SP	40	16·1	0·82	24	19·1	0·49	17	17·4	0·83	25
	10 DCP	40	14·8	0·81	20	16·7	0·45	14	18·5	0·81	25

TABLE 9. *Field Comparisons of Super, Serpentine-super, Dicalcium Phosphate, Silicophosphate, Mineral Phosphate, and Semsol at Centres 9—Granitic, and 17—Basic*

	Centre 9				*Centre 17*		
Phosphate	P_2O_5-*rate lb.*	*Swedes (tons)*	P_2O_5 *% DM*	P_2O_5-*uptake lb.*	*Phosphate*	P_2O_5-*rate lb.*	*Potatoes (tons)*
..	0	7·3	0·41	5	..	0	5·3
1 S	20	15·2	0·70	17	1 S	40	9·0
7 SS	20	15·0	0·39	9	4 SP	40	8·4
19 MP	20	13·4	0·43	12	10 DCP	40	9·0
1 S	40	16·8	0·58	14	20 GMP	40	6·1
7 SS	40	16·3	0·41	14	24 Sem	40	7·2
19 MP	40	14·7	0·50	15	1 S	80	11·7
½ 1 S+ ½ 19 MP	40	15·9	0·67	21	4 SP	80	10·9
1 S	140	19·9	0·83	32	10 DCP	80	11·0
					20 GMP	80	6·7
	S.E.	±0·92			24 Sem	80	8·2
					1 S	120	11·3

TABLE 10.* *Pot Comparisons of Super, High-temperature Phosphates, and Metaphosphate in Soil–sand Mixtures*

		Straw+Grain	
Phosphate	P_2O_5-*rate*	*DM*‡	P_2O_5-*uptake*‡
..	0·00	18·3	0·045
1 S	0·10	30·3	0·071
5 Meta	0·10	22·1	0·064
2 C	0·10	29·0	0·072
3 F	0·10	29·5	0·070
1 S	1·24	85·0	0·261
5 Meta	1·24	63·7	0·190
2 C	1·24	62·8	0·161
3 F	1·24	58·5	0·197

* All pot data are expressed in grammes per pot.
‡ Averages of values for soils from centres 1, 3, and 6.

TABLE 11. *Pot Comparisons of Super, Super-dolomite, and Coprolite in Sand and Soil–sand Mixtures*

Phosphate	P_2O_5-*rate*	*Straw+Grain*			
		DM		P_2O_5-*uptake*	
		Sand	*Soil–sand mixtures**	*Sand*	*Soil–sand mixtures**
..	0·00	3·1	17·3	0·005	0·060
1 S	0·10	41·3	27·7	0·055	0·086
6 SD	0·10	28·2	29·0	0·036	0·095
18 GC	0·10	15·7	20·2	0·027	0·073
1 S	0·20	63·2	40·7	0·125	0·122
6 SD	0·20	54·2	36·0	0·073	0·115
18 GC	0·20	18·0	24·1	0·028	0·081
1 S	1·00	76·1	79·5	0·493	0·330
6 SD	1·00	74·3	79·8	0·260	0·290
18 GC	1·00	22·5	34·0	0·025	0·108

* Averages of values for soils from centres 4 and 5.

TABLE 12. *Pot Comparisons of Super, Serpentine-super, Super-lime, Silicophosphate, Dicalcium Phosphate, Gafsa Phosphate, and Semsol in Sand and Soil–sand Mixtures*

Phosphate	P_2O_5-*rate*	*DM—Straw+Grain*	
		*Soil–sand mixtures**	*Sand*
..	0·00	17·0	11·8
1 S	0·10	31·8	46·1
4 SP	0·10	30·4	39·5
10 DCP	0·10	29·4	50·7
9 SL	0·10	31·0	47·7
8 SS	0·10	32·0	38·7
20 GMP	0·10	28·6	36·4
24 Sem	0·10	24·4	31·7
1 S	0·20	45·4	..
4 SP	0·20	39·3	..
10 DCP	0·20	40·5	..
9 SL	0·20	44·8	..
8 SS	0·20	44·5	..
20 GMP	0·20	36·5	..
24 Sem	0·20	33·5	..

* Averages of values for soils from centres 14, 15, 16, and 17.

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THE THREE-QUARTER-BRED HOLSTEIN-ZEBU HEIFER

Pt. I. BLOOD CHANGES DURING THE FIRST YEAR OF LIFE

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MANY attempts have been made to establish temperate-zone breeds of dairy cattle in the tropics and sub-tropics. In general the results have been unsatisfactory because of degenerative changes in the imported stock, particularly in their offspring. As Hammond [1] pointed out in his survey of cattle-breeding in Trinidad and Jamaica, degeneration is more likely and more intense in herds that are unsatisfactorily managed or inadequately nourished; nevertheless, the main cause of degeneration is probably the physiological incapacity of such breeds to tolerate the high temperature and, in some regions, the high humidity of the tropics. In this connexion the studies of Rhoad [2, 3] are of particular interest. He found that the temperate-zone breeds were strikingly inferior to tropical cattle of Zebu type in their capacity for dissipating body heat. The ability of cross-bred animals to dissipate heat, as judged by the rise in body-temperature on exposure to direct sunlight, was closely related to the proportion of Zebu blood in the animals studied—those with a low proportion having poor heat tolerances similar to those of temperate-zone breeds.

The Zebu breeds, on the other hand, are well suited to tropical conditions and suffer little from high atmospheric temperature and humidity; but for the most part their productive performance as dairy animals is inferior. The Sahiwal (Montgomery) breed, which has been moderately successful as a milk producer in India, is an exception.

From observations on *Bos taurus* (temperate zone) and *Bos indicus* (tropical zone) and on animals resulting from cross-breeding with these species, various workers have recommended that attention should be given to developing tropical breeds of cattle that combine the capacity to produce milk or beef, as in *Bos taurus*, and the ability to withstand heat, as in *Bos indicus*. Cross-breeding to yield animals containing approximately one-quarter of Zebu blood has generally been found to produce animals of a suitable type [4, 5, 6, 7, 8, 9].

In Trinidad the cross has been effected with pure-bred Holstein-Friesian bulls, imported from the U.S.A. and Canada, and local Zebu cows. The Zebu commonly available are of the Nellore type, although their purity may sometimes be in doubt because of the possibility of a distant outcross to a *Bos taurus* breed followed by repeated back-crossing of successive generations to Zebu. The half-bred animals of the first cross often exhibit marked heterosis and excitability. The three-quarter-bred animal, produced by crossing the half-bred cow with a pure-bred Holstein-Friesian bull, is usually more suitable as a dairy animal both from the standpoint of milk production and that of temperament.

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No study of the haematology of this type of cross-bred dairy heifer has been reported and we thought it of interest to determine how far the haematology of the three-quarter-bred Holstein-Zebu resembled those of the parent species in their respective environments, especially since it has been suggested that certain blood characteristics are associated with ability to withstand the exigencies of tropical climates. In addition it was necessary to establish standards of normality and estimates of variability with which to compare values obtained in subsequent investigations of the effect of various methods of feeding and management on the Holstein-Zebu calf.

Experimental

The haematological observations formed part of an experiment designed to determine the growth-response, and later the reproductive performance, of Holstein-Zebu calves rationed and managed according to temperate-zone standards. The work on growth and reproduction will be reported in a later communication.

In the study 18 animals were used, of which 13 were three-quarter-bred. The remaining 5 contained a slightly higher but not accurately determinable proportion of *Bos taurus* blood, because their foundation dams were impure Zebu.

Blood samples were always drawn from the jugular vein at 8.30 to 9 a.m., potassium oxalate being used as anti-coagulant. Up to 6 months of age samples were drawn weekly, thereafter at 2-weekly intervals. The mean monthly value was obtained by averaging the month's observations for each animal. Some workers [10, 11] have preferred to draw several samples at regular intervals during the day to eliminate the effect of diurnal variations when establishing standard values for blood constituents.

We ourselves had observed sporadic appearances of transitory anaemia in calves of this type in Trinidad and therefore adopted weekly sampling to avoid the possibility of including the low values which mark the recovery stage of such attacks. In the present study 9 such cases were observed and the values obtained at such times were excluded from the calculation of monthly average values. The anaemic attack, which is commonest in calves under 6 months of age, lasts for 1 or 2 weeks, and if weekly samplings are made, can be predicted by the previous appearance of icterus together with a positive van den Bergh reaction. No explanation of the condition is offered. Since the anaemia is of the blood-destructive type it may be a consequence of tick infestation. However, it is not found in all infested calves, and its incidence does not appear to be related to the degree of infestation.

Methods

Erythrocytes and leucocytes were enumerated with an American Standard Haemocytometer with a Levy counting-chamber and Improved Neubauer ruling. Thoma pipettes were used for dilution and Hayem's fluid as the diluent for erythrocytes. The counts were made by enumerating the cells in 5 groups of 16 of the smallest squares and

the same 5 groups were used throughout the study. For leucocyte counts 3 per cent. acetic acid with a few drops of gentian violet was used as the diluent. The leucocytes in the entire cross-ruled area were counted. Total erythrocyte volume was determined with haematocrit tubes. These tubes, 100 mm. long, were made by annealing the end of stout-walled glass tubing of 1 mm. bore. After being filled with a capillary pipette the tubes were centrifuged until there was no further reduction in the packed-cell volume, as measured by a millimetre rule and a magnifying

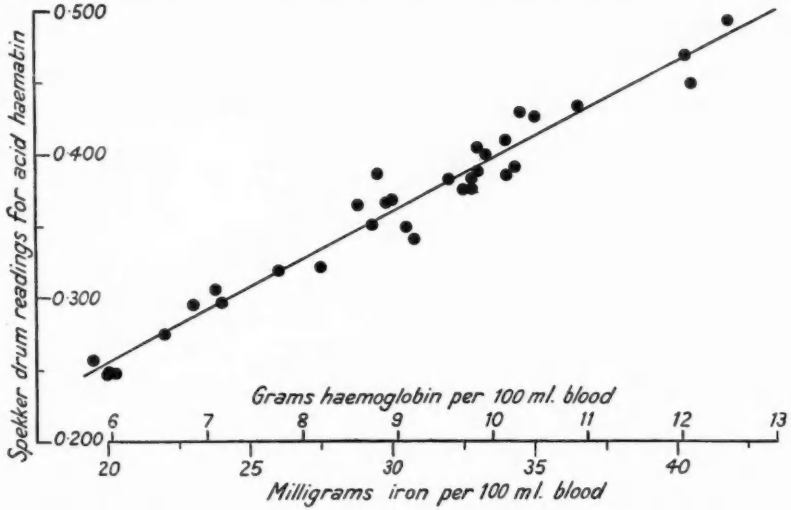

FIG. 1. The relation between Spekker absorptiometer drum readings and haemoglobin iron, including the calculated haemoglobin equivalent of the iron.

lens. Complete packing required about 4 hours at about 3,000 r.p.m. All determinations were made in duplicate.

The determination of haemoglobin raised special problems. Clinical methods of determination as commonly practised were not sufficiently accurate for the present purpose of establishing standards to serve as a basis of comparison in future studies. The acid-hematin method of estimation was adopted with the precautions recommended by Ponder [12], who in his studies of human blood noted that large errors might arise from the long and variable time required for full development of the hematin colour. Preliminary studies confirmed Ponder's observation that the customary interval of 30 min. is inadequate for full colour development. Instead, a period of 90 to 120 min. was required. All colour measurements were made with a Spekker absorptiometer with 1 cm. cells and filter O.B. 2.

To formulate the equation relating the drum readings of the absorptiometer to quantities of haemoglobin, a series of blood samples was analysed by the acid-hematin method for haemoglobin and by a

modification of the aa'-dipyridyl method, which will be published elsewhere, for total blood iron. In calculating the haemoglobin equivalent of the blood iron we used the value 336 mg. iron per 100 gm. haemoglobin.

Results

Conversion of Spekker drum readings to haemoglobin.—The results of study of 33 cases are given in Fig. 1. The drum readings are plotted against a double scale which shows both the absolute iron values found on analysis and the haemoglobin equivalent of these values. The regression equation: $X = 0{\cdot}0353y + 0{\cdot}045$, where X is the drum reading and y the quantity of haemoglobin per 100 ml. of blood, defines the relation.

Of the 33 cases studied 20 gave values within ± 3 per cent. of the values expected from their iron-content, 7 were in error by more than ± 3 per cent. but less than ± 5 per cent., and the remaining 6 cases were in error by more than ± 5 per cent. The largest deviation from the regression line was 9 per cent.

Erythrocytes.—The average monthly values, obtained by averaging the mean monthly values of individual calves, together with the coefficients of variation, calculated also from mean monthly values, are given in Table 1. The changes in the red-cell count may be divided into three

TABLE 1. *Haematology of the Three-quarter-bred Holstein-Zebu Calf during the First Year of Life*

Age (months)	*Erythrocytes (millions per cu. mm.)*	*Coefficient of variation (per cent.)*	*Leucocytes (thousands per cu. mm.)*	*Coefficient of variation (per cent.)*	*Haemoglobin (gm. per 100 ml.)*	*Coefficient of variation (per cent.)*	*Packed-cell volume (per cent.)*	*Coefficient of variation (per cent.)*
0–1	8·4	15·5	10·4	23·1	10·3	14·6	29·5	16·3
1–2	9·0	8·9	10·3	33·0	10·0	8·0	29·5	8·2
2–3	9·0	22·2	12·2	22·9	10·2	10·8	30·9	13·3
3–4	9·0	21·1	13·9	26·6	10·4	11·5	30·3	12·5
4–5	8·0	17·5	13·7	24·1	9·7	10·3	28·2	8·9
5–6	7·9	13·9	14·5	25·5	9·7	10·3	27·8	9·0
6–7	8·0	17·5	13·5	21·5	9·6	11·5	27·9	12·2
7–8	7·7	16·9	13·8	17·4	9·1	12·1	27·1	11·4
8–9	7·4	18·9	14·0	19·3	9·0	11·1	26·7	12·0
9–10	7·7	16·9	14·8	21·6	9·3	6·5	27·5	10·9
10–11	7·1	14·1	13·5	21·5	8·9	6·7	26·8	8·2
11–12	7·3	17·8	14·7	20·4	9·3	7·5	27·6	10·9

periods. The first period, which lasted from birth until about 4 months of age, was characterized by a slight increase in cell-count, after which the level remained steady. This also represented the milk-feeding period. The second period was from 4 to 8 months of age, approximately, when the red-cell count declined slightly. The final period, up to 12 months of age, was characterized by cell-counts of about 7 to 7·5 millions per cu. mm. of blood.

Leucocytes.—The white-cell count remained steady during the first 2 months of life, increased during the third month, and thereafter ranged irregularly between the limits of 13,500 and 14,800 per cu. mm. of blood.

Haemoglobin.—The haemoglobin-content of the blood varied in a manner roughly parallel with the red-cell count. Up to about 4 months of age the concentration of haemoglobin in the blood remained at a fairly constant level close to 10 gm. per 100 ml. During the next 3 months it declined and thereafter was little above 9·0 gm. per 100 ml.

Packed-cell volume.—The values were highest during the first 4 months of life. Thereafter they ranged about a slightly lower level.

Coefficients of variation.—The leucocyte-count showed the greatest variability. The erythrocyte-count also showed about the same variability at all ages studied. The haemoglobin values showed the smallest variability.

Discussion

A survey of the literature on the haematology of *Bos taurus* and *Bos indicus* cattle yielded the data given in Table 2. The observations in young stock are not extensive and no study with closely spaced serial examinations seems to have been made. Comparison of the erythrocyte

TABLE 2. *Haematology of* Bos taurus *and* Bos indicus *cattle, as given in published work*

Breed	*Locality*	*Description*	*Haemoglobin (gm. per 100 ml.)*	*Erythrocytes (millions per cu. mm.)*	*Leucocytes (thousands per cu. mm.)*	*Reference*
Bos taurus						
Mixed	Kansas, U.S.	Calves	10·5	..	..	[13]
Mixed	Pennsylvania, U.S.	Calves below 1 month	14·4	..	..	[30]
		Calves 1 to 5 months	12·2	..	..	,,
		Calves 6 to 10 months	14·0	..	..	,,
Mixed	Kansas, U.S.	Heifers	11·7	..	..	[13]
		Cows	10·9	..	..	,,
Mixed	England	Cows	11·5	..	..	[15]
Mixed	Pennsylvania, U.S.	Cows	13·2	..	..	[30]
Jersey	Florida, U.S.	Cows	13·3	..	..	[10]
Mixed	Florida, U.S.	Cows	11·3	..	..	,,
Mixed	New York, U.S.	Cows	10·9	..	..	[16]
Mixed	England	Calves at birth	..	7·9	10·0	[17]
		Calves below 1 month	..	6·0	10·0	,,
		Calves 2 to 4 months	..	8·1	8·5	,,
		Calves 4 to 6 months	..	7·3	9·2	,,
		Calves at 12 months	..	5·3	5·3	,,
		Cows	..	6·2	8·1	,,
Mixed	U.S.	..	..	6·3	7·9	[18]
Mixed	New Zealand	..	..	7·6	5·6	[19]
Bos indicus						
Red Scindi	Philippines	Cows	12·6	..	..	[20]
Nellore	Philippines	Young cattle	8·7	..	..	[11]
Nellore	Philippines	Adult cattle	9·9	..	..	[21]
Nellore	Philippines	Adult cattle	9·8	..	..	[22]
Nellore	Philippines	Adult cattle	10·2	..	..	[11]
Mixed	Tanganyika	Adult cattle	11·9	..	..	[23]
Mixed	Uganda	Adult cattle	11·7	8·8	10·9	[24]
Hariana	India	Calves 0 to 6 months	15·7	13·2	14·4	[14]
		Calves 6 to 12 months	13·5	11·5	13·3	,,
		Heifers 1 to 2 years	..	10·2	11·5	,,
		Adult cattle	11·0	8·1	9·0	,,
Scindi	India	Bulls	..	9·3	..	[25]
		Cows	..	8·5	12·8	,,
Gir	India	Cows	..	8·9	12·0	,,
Half-bred	India	Cows	..	6·9	11·2	,,

and leucocyte counts of the two species presents no serious difficulty. Although individual counts show moderate errors the standardized technique in this field makes large systematic errors unlikely. The situation is quite different for haemoglobin estimation, because fading of the so-called permanent standard in the form of glass disks or sealed tubes of coloured solutions introduces a systematic error—up to 20 per cent. in standard glass disks, as one of us has observed.

The values in Table 2 do not suggest that there is any species difference between the circulating haemoglobin of *Bos taurus* and *Bos indicus* cattle. Within the Zebu group the Nellore breed appears to be lower in haemoglobin than other cattle; but this difference may result from some other factor, since the low values all fell within one area, the Philippines. Haemoglobin values are higher in very young calves of both species than in the corresponding adults. Unfortunately the data are insufficient to indicate the age when the higher give place to the lower values.

The erythrocyte-count of young Zebu calves is much higher than that of *Bos taurus* calves; that of adult cattle is notably higher in *Bos indicus* than in *Bos taurus*. In *Bos taurus* the first year covers the transition from the higher values in young calves to the lower adult values, whereas in *Bos indicus* cattle the transition period appears to be longer; but the data are not sufficiently extensive to demonstrate a definite species difference with certainty.

The leucocyte-count is markedly higher in Zebu animals at all ages. Within each species the values are highest for young calves and lowest for adult animals.

The haematology of the three-quarter-bred Holstein-Zebu calf during the first year of life shows certain changes which are common to both parent species and others that appear to be unique. As in both the parent species, the haemoglobin concentration decreased with advancing age; but in contrast to the parent species the concentration of haemoglobin is markedly lower. The more extensive surveys for *Bos taurus* cattle place the average adult value at about 11·5 gm. per 100 ml.; but our figures for the average concentration of haemoglobin never approached this value, even in calves. The difference between our values and those of calves of corresponding age of either parent species was, of course, even more striking. In general, calves of both parent species had a haemoglobin level approximately 50 per cent. higher than that of the Holstein-Zebu calves.

It is unlikely that the low values recorded in the present investigation arose from a systematic error. The range of error observed in the study of the acid-hematin method, referred to above, agrees closely with that of Ponder [12], who also compared the ratio of acid-hematin colour development to haemoglobin iron. It appears that individual values for haemoglobin may be in error by as much as 10 per cent.; average values probably do not err by more than 5 per cent. Moreover, our values for haemoglobin iron are well below the values given for this constituent in Zebu cattle by Gonzaga [20] and by Mullick and Pal [14].

It is noteworthy that the haemoglobin levels reported for young and adult Zebu of the Nellore breed in the Philippines are similar to those

for our calves which contained about one-quarter of Nellore blood. Whether the low value observed by the Philippine workers is generally true of Nellore cattle or peculiar to the breed in those islands is uncertain.

The erythrocyte-count approximated more closely to that of *Bos taurus* calves than to that of *Bos indicus* calves during the first year of life. In general the numbers were well below the corresponding Zebu values but slightly above the *Bos taurus* values. Since the red-cell counts lie between the values for the two parent species whilst the haemoglobin levels are considerably lower than in the parent species, it seems that there may be differences in red-cell size and haemoglobin-content. The data given in Table 3 were calculated from those in Table 1.

TABLE 3. *Changes in the Mean Corpuscular Volume and the Mean Corpuscular Haemoglobin of the Three-quarter-bred Holstein-Zebu Heifer Calf during the First Year of Life*

Age in months	*Mean corpuscular volume (cubic microns)*	*Mean corpuscular haemoglobin (micromicrograms)*
0–1	35·1	12·3
1–2	32·8	11·1
2–3	34·3	11·3
3–4	33·7	11·6
4–5	35·2	12·1
5–6	35·2	12·3
6–7	34·9	12·0
7–8	35·2	11·8
8–9	36·1	12·2
9–10	35·7	12·1
10–11	37·7	12·5
11–12	37·8	12·7

After initial reductions from the values found during the first month of life, both the mean corpuscular volume and the mean quantity of haemoglobin in the erythrocyte increase. The regression on time is highly significant ($t = 4{\cdot}76$, $P < 1$ per cent.) in the case of mean corpuscular volume and significant ($t = 2{\cdot}665$, $P < 5$ per cent.) in the case of mean corpuscular haemoglobin. But the principal interest lies in comparisons with data for the parent species. Boddie [26] gives the value 49 ± 6 cubic microns as the corpuscular volume for English cattle. His data also yield the value of 19·3 micromicrograms of haemoglobin per erythrocyte. It will be noted that all the values for mean corpuscular volume of the erythrocyte of the Holstein-Zebu are well below this value. Comparable data for Zebu cattle are lacking. Similarly the mean corpuscular haemoglobin values for the cross-bred heifers are all much less than those calculated from Boddie's data. The corresponding Zebu values, calculated from data in Table 2, are (micromicrograms): calves of 0 to 6 months of age, 11·9; calves 6 to 12 months of age, 11·8; Hariana adult cattle, 13·6; Uganda mixed breeds, 13·3. These are closely similar to our values for Holstein-Zebu values. Further, the average quantity

of haemoglobin per cubic micron of erythrocyte in the cross-bred calves was 0·34 micromicrograms compared with 0·39 for English cattle, indicating that the reduction in mean haemoglobin per corpuscle is greater than can be accounted for by the reduced size of the corpuscle of the Holstein-Zebu animal. Data for Zebu cattle are inadequate for calculation of comparable values.

The trend in the leucocyte-count during the first year of life in the three-quarter-bred calves was of particular interest, being distinct from that of both parent species. In place of the reduction in white-cell count showed by *Bos taurus* and *Bos indicus* calves during early life an increase occurred. The initial values for our calves were similar to those of *Bos taurus* calves; the values towards the end of the first year were similar to those of *Bos indicus* heifers of the same age.

An extensive haematological survey of Brazilian cattle was recently made by Villares [27], who found that the native Brazilian race, the Caracu, had an average red-cell count of over 8 millions per cu. mm. Imported Dutch Friesians, Normandy cattle, and Guernseys showed values of 5, 6, and 7, respectively. Descendants of imported cattle tended to have higher erythrocyte-counts than their ancestors. Villares considered that an ability to withstand the effects of a tropical climate was associated with a high red-cell count. If such a relation exists the physiological explanation remains obscure. Our findings indicate that the higher counts are associated with smaller cell-size, at least in three-quarter-bred heifers. Oxygen transport should be facilitated by the relatively greater area of cell-surface exposed, but it is difficult to see how this characteristic is related to heat tolerance. We have shown elsewhere [28] that three-quarter-bred heifers are markedly inferior to Zebu in their capacity to dissipate body heat, although superior to temperate-zone cattle under tropical conditions.

Sankaranarayanan [25] suggested that the red-cell count of cross-bred animals was governed by their proportion of Zebu blood. His value for half-bred cows, given in Table 2, is approximately mid-way between the values for the parent species. His data on other animals with different proportions of Zebu blood are too few to warrant emphasis. That the problem is more complex is suggested by the findings of Norris and Chamberlain [29] and Josland [19]. Norris and Chamberlain observed values of 10·3 million red blood-cells per cu. mm. for calves, heifers, and bullocks, and of 7·8 millions for adult cows. In a study of temperate-zone cattle in Australia, Josland [19], working in New Zealand, gave the value of 7·6 millions. The high values for Australian cattle suggest that increases in red-cell count may arise simply as a result of the operation of climatological factors.

Summary

The changes in red-cell count, white-cell count, haemoglobin, and packed-cell volume of the blood of three-quarter-bred Holstein-Zebu heifers during the first year of life were studied.

The haemoglobin-content of the blood was lower than that of either of the parent species, in their respective normal environments.

The red-cell count was lower than in Zebu and approached the value for temperate-zone cattle. The count decreased during the first year of life.

The white-cell count increased during the first year of life in contrast to the parent species, which both show decreases. The ultimate level reached was similar to that of Zebu.

The volume of the red cell was less than that of temperate-zone cattle. The average size of the red cell increased during the first year of life.

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RESISTANCE OF WHEAT TO SPROUTING IN THE EAR: PRELIMINARY INVESTIGATIONS

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UNFAVOURABLE climatic conditions in the British Isles at harvest-time may cause considerable sprouting of wheat in the ear, both in the field and stook, with consequent loss to the national economy because sprouted grain is unsuitable for seed or for the manufacture of flour. Greer and Hutchinson [1] drew attention to the tendency of several popular varieties, especially amongst the white wheats, to sprout readily in the field, whereas some red wheats showed marked resistance under similar circumstances. They suggested that the resistance factors were related to the dormancy of the grain at harvest. Thus some varieties, although judged to be fully ripe by the usual physical characteristics of colour, &c., were dormant in the sense that they were not yet fully mature as seeds, and would not germinate readily under normal conditions of temperature and moisture until they had undergone an after-ripening or maturation process. This state of dormancy varies greatly from one wheat to another, being least evident in certain white varieties. Drying or storage hastens maturation and, in general, the varieties showing the strongest dormancy require longer periods of storage. The rather indefinite period between harvest-ripening and maturation is termed by Continental writers 'the post-harvest maturation period'.

Much attention has been given both on the Continent and in the U.S.A. to the subject of sprout-resistance in cereals, and at the Svälof Institute, Sweden, several varieties of wheat and barley that are claimed to be highly resistant have been evolved. Nilsson-Ehle [2] suggested that, in wheat, varietal differences in the capacity to germinate readily at harvest-time are conditioned by hereditary factors, especially those which control red coloration in the testa. Consequently white wheats, which lack any factor for redness, germinate readily, and those wheats with many factors for redness do not.

Later work by Åkerman [3] and Feekes [4] confirmed that red-grained wheats are more resistant to sprouting and that there is a genetic linkage between the factors for redness and resistance to sprouting in the ear. That the latter phenomenon is a varietal characteristic connected with the length of the so-called post-harvest maturation period was suggested by Harrington [5], Navolotskii and Navolotskaja [6], Kondō, Isshiki, and Terasaka [7], and Feekes [4]. Nikolaenko [8], however, was unable to confirm the superior sprout-resistance of red wheats and, instead, suggested that there was a correlation between sprout-resistance and resistance to *Fusarium rostratum* plus length of period from earing to maturity. Hoyke [9] studied the role of the different parts of the wheat grain during the post-harvest maturation period and concluded that ripening in wheat is related to processes in the pericarp.

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Our own experience (extending over at least two very distinct types of season conducive to sprouting) suggests that sprout-resistance is governed by hereditary factors, but that the plant-breeder can make only slow progress in the breeding of new varieties until reliable methods are available for estimating sprout-resistance. The reliability of such methods must of course depend considerably upon our knowledge of the mechanism of this resistance. During the past three years data on the problem have been collected independently by our two laboratories, but early in 1945 it was decided to collaborate in further work, including the development of a suitable laboratory technique for the assessment of the sprouting propensities of wheat, particularly of hybrid material in course of development.

Experimental

Six established wheat varieties and 7 hybrids still in process of development prior to field-scale trials were used in these experiments. All the wheats were subjected, at Cambridge, to the laboratory tests described later, whilst tests were also being made at St. Albans upon 5 of the varieties. Three white-grained and 10 red-grained lines were included. The wheats were all grown on the Headquarters Trial Ground of the N.I.A.B., with one exception, which was grown only a few miles away; climatic conditions before and during the harvest period were therefore fairly similar for all the stocks used. The occurrence of strictly identical climatic conditions is unlikely even in one locality, as differences exist between the varieties both in the date of onset and of ripening. The weather, however, throughout this period was consistently wet and cool with no pronounced change at any time to the sunny warm conditions normally associated with harvest weather, and thus both the later and the earlier varieties ripened under comparable conditions.

Random ear-samples of 9 varieties were taken from the field at intervals before and after full ripening, whilst the other 4 were sampled first at the fully ripened stage and thereafter 2 or 3 times within the next 17 days. The stage at which the grain was fully visibly ripe, i.e. grain-hard and typically coloured, was taken as the datum line for comparative purposes and is described as the fully ripe stage.

In each case the undried grain was removed from the ear by hand immediately after collection of the ear-sample and germination tests commenced at once, 6 separate hundreds of each variety being planted on damp sterile sand and incubated at constant temperature, 3 at 15° C. and 3 at 23° C. Daily records were kept of all the seeds which had begun to germinate. For the experiments at St. Albans the unthreshed ears were at once transported in closed bottles from Cambridge, the planting taking place 4 hours later.

Testing of grain in the ear.—Owing to the unknown influence of the ear itself, present in the field but absent in threshed grain as tested in the laboratory, a limited investigation was made at St. Albans of the method of assessing sprout-resistance by experiments upon grain in the ear. The ears were mounted on stiff wires set up vertically in turf under a small cage and were heavily sprayed for 2 hours at least 3 times (some-

times 4 times) daily, but were otherwise exposed to the normal fluctuations of the weather. A period of 7 days was found adequate to induce sprouting of a large percentage of grains of the less resistant varieties. At the end of this time the grain was removed from the ears, the percentage of sprouted grains determined, and in some cases the unsprouted grain tested for moisture-content. In these tests, all the varieties and hybrids grown at Cambridge were used together with a further series of varieties grown in small plots at St. Albans.

Results

Seed-testing experience had established that germination tests of dormant wheat, made at relatively low temperatures, materially assisted in breaking dormancy, whereas germination tests at relatively high temperatures tended to accentuate its effects. In our experiments there was a marked difference in behaviour at the two temperatures employed, especially in the very dormant grain, but the differences narrowed as maturation progressed. A progressive increase in the speed and extent of germination was observed at each successive sampling, except where secondary dormancy appeared to develop.

A comparison of the results at various stages of grain-development demonstrated a clear difference between the white- and red-grained wheats examined, the former reaching the stage of 'germinating ripeness' more quickly than the latter. The differences in the rate of maturation were most marked at the fully ripe stage. Figs. 1 and 2 show the results of the germination tests made at 15° and 23° C. respectively upon seed from ear-samples at this stage. Total germination is plotted from the first up to the tenth day from the planting of the seed in sand. Certain varieties were still dormant at the date of the last ear-sample taken, some 14 days after the fully ripe stage had been reached; that the seed was viable, though still dormant, was demonstrated by maintaining seed at 40° C. for 2 days, and then germinating by the methods already described. Germination following this treatment was rapid and complete.

The 3 white wheats included in the experiment were markedly less dormant than the red. This difference was apparent at each germination temperature, being more pronounced at 23° C. Differences in degree of dormancy amongst both white and red wheats were apparent at both 15° and 23° C.

Of the white wheats, the hybrid 241/12B was least dormant. Holdfast and Juliana were rather more dormant, the latter more than the former. Amongst the red wheats Scandia was the least and Jubilegem the most dormant. The relative behaviour of the other red wheats was not precisely similar at each germination temperature. Yeoman, although showing the same degree of dormancy as Scandia at 15° C., was only slightly less dormant than Jubilegem at the higher temperature.

Results of ear-tests.—The varieties tested could be divided into three groups:

1. In which the grain sprouted readily in the ear. This group includes the common white wheats, Holdfast, Juliana, &c.

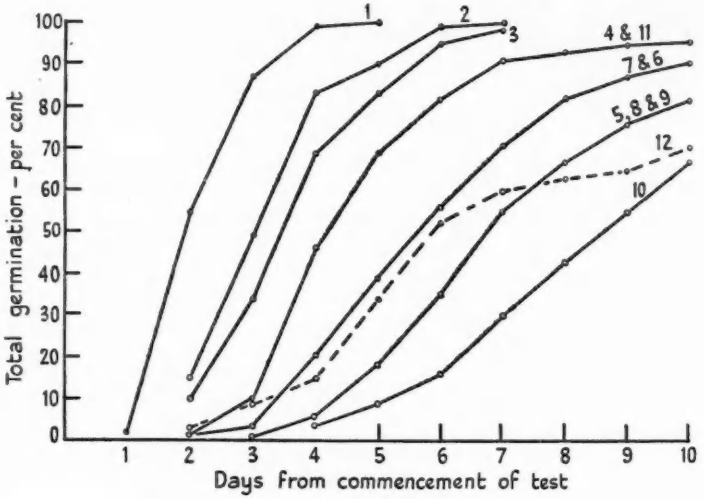

FIG. 1. Laboratory germination tests at 15° C.

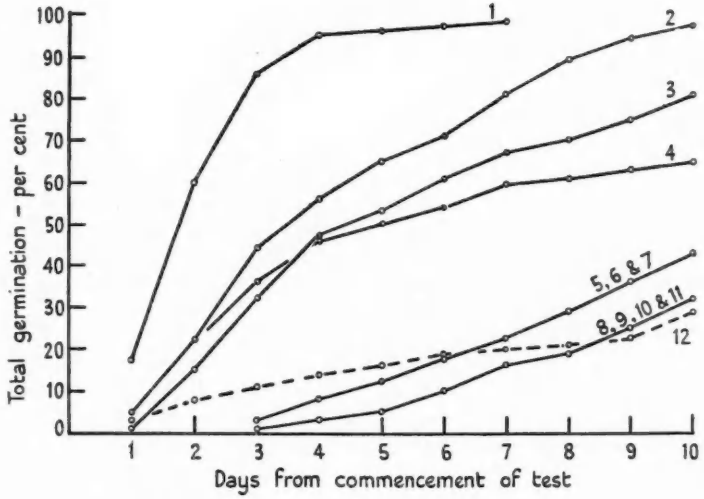

FIG. 2. Laboratory germination tests at 23° C.

1 = 241/12B
2 = Holdfast
3 = Juliana
4 = Scandia
5 = 298/16A
6 = 298/12A
7 = 298/9B
8 = 298/9A
9 = 298/15C
10 = Jubilegem
11 = Yeoman
12 = Squarehead's Master

2. Those in which the grain sprouted irregularly in the ear but grew readily after threshing if placed for about 24 to 36 hours in a closed tin to prevent moisture-loss, e.g. Yeoman, Scandia.
3. In which the grain neither sprouted in the ear nor grew with any regularity after threshing, even though sufficient moisture was present, e.g. Atle, April Bearded, and Hen Gymro.

A preliminary trial carried out between August 16 and 23 on the varieties and hybrids grown at Cambridge gave the results shown in Table 1, col. 1. The results of a second trial on some of these varieties are indicated in col. 2. Col. 3 shows the results of 4-day pot-germination tests of the threshed grain at field temperatures alongside the ears.

TABLE 1. *Difference in Germination between Unthreshed and Threshed Grain*

	Percentage germination		
	Unthreshed grain		
	First expt.	*Second expt.*	*Threshed grain*
241/12B (white) . .	100	93	100
Holdfast (white) . .	90	..	98
Juliana (white) . .	90	..	94
298/16A . . .	32	40·5	86
S.H.M. 13/4 . .	19	28	53
Scandia. . . .	17·5	23	54
Yeoman . . .	17	..	98
298/12A. . . .	17	31	94
298/15C. . . .	10·5	6·5	92
298/9A	8·5	6·5	93
218/37B. . . .	4	8	95
298/9B	3	10	93
Jubilegem . . .	1	6	44

A record of the temperatures prevailing throughout the first test indicated that the average was about 15° C., being at night below rather than above this temperature. Normal laboratory germination tests of the threshed wheats were made at the same time, at both 15° and 23° C., and tests were also made in pots placed outside near the test-cage. Results in the latter set of tests were similar to those at 15° C. and indicated that the unthreshed grain in ear was much more resistant to sprouting than the threshed grain at similar temperatures (see Table 1, col. 3). The order of resistance amongst the varieties was remarkably similar to that of the threshed grain at 23° C.

Third and fourth trials were carried out 3 weeks later, on September 12 and 24, using a more extended series of wheat varieties. The ears had been stored dry in the laboratory for 3 weeks (grain contained about 14–15 per cent. moisture), and in most of them maturation of the grain as adjudged by laboratory germination tests of threshed grain at 15° C. (and in several cases even at 23° C.) was complete. Thus, in all but the most dormant varieties, differences in resistance to sprouting at

this stage are not independent of the influence of the ear. The results of the third trial are shown in Table 2, col. 1, which again indicate a marked distinction between red and white varieties in their resistance to sprouting and also point to differences between the white wheats themselves. This was confirmed in the fourth trial, Table 2, col. 2, which indicates a greater resistance in Warden and Victor than in Holdfast and Juliana. In another test one further point was investigated. Many farmers contend that varietal differences in relation to sprouting in the ear are connected with the ear-shape and habit. It is contended that the erect, dense-eared varieties hold water in the ear to a greater extent than tall lax types in which the partial inversion of the ear permits better drainage and its laxer habit permits quicker drying between showers. To test this assertion, half the ears mounted for the experiment were placed in an inverted position and counted separately at the conclusion. The results for normal and inverted ears are shown in cols. 3 and 4 respectively, whilst col. 5 shows the results obtained from ears of Juliana made lax by removal of alternate spikelets.

TABLE 2. *Germination of Grain in the Ear*

Variety	*Percentage germination*				
	Third expt.	*Fourth expt.*	*Upright ears*	*Inverted ears*	*Ears made lax*
Holdfast	79	93	90	95	..
Steadfast	74	..	..	..	..
Juliana	82	80	78	81	70
Warden (white)	43	53	63	43	..
Victor (white)	30	56	55	57	..
Little Joss	30	..	..	..	..
Weibull's Standard	20	..	..	..	..
Redman	18	17	26	8	..
Squarehead's Master	11	..	..	..	..
Desprez 80	7	..	..	..	..
Scandia	7	..	..	..	..
Jubilegem	4	51	55	47	..
April Bearded	0	..	..	..	..
Atle	0	..	..	..	..
Hen Gymro	0	..	..	..	..

Although these figures suggest slightly less germination in the inverted ears, the differences are, in the main, within experimental error. It would seem that any influence of ear-habit is completely overshadowed by the condition of the grain within the ear.

For the September series of experiments the results of germination tests of threshed grain made in pots placed outside at the prevailing field temperatures are not available in all cases. Nevertheless the laboratory tests at 15° and 23° C. upon these varieties over the relevant period conclusively showed that, in the first 3 wheats, provided there was adequate water-supply, little or no dormancy was apparent at 15° C. or even at 23° C.; there was some evidence suggesting that where mild dormancy exists it can be accentuated by restriction of water-supply.

In the intermediate group, although slight dormancy was apparent at 15° C., especially as one progressed down the table from Victor to Scandia, there was an increasing degree of apparent dormancy at 23° C., which can, qualitatively at least, be correlated with the increasing degree of resistance to sprouting in the ear at the much lower temperatures prevailing in the field. Qualitatively, too, as the maturity of the ears increased with storage, as adjudged by the laboratory germination tests of the grain at 23° C., so did their susceptibility to sprouting within the ear in the field. This was specially marked in Jubilegem, where the sprout-resistance in the field (col. 1) was largely lost after 12 days' storage (col. 2), the change coinciding with a very marked loss of dormancy in laboratory tests of threshed grain at 23° C. The last 3 wheats were markedly dormant in the threshed state not only at 23° C., but even at 15° C., and although on further storage maturity increased slowly, especially at 15° C., it was still marked at 23° C. several weeks after the ear-tests were concluded.

Although the weather was very wet, in fact abnormally so, throughout most of the tests, it was obvious from moisture determinations of grain taken from several ears exposed in similar manner to the rain, but without artificial spraying, that it is not easy to reach and to maintain in standing corn a moisture-level within the grain itself sufficient to permit rapid sprouting. This initial level is difficult to determine, but is of the order of 33 per cent., and it rapidly increases as sprouting progresses, so that adequate supplies of water must be available after the process commences. Drainage and the drying effect of winds between showers are very effective in tending to keep the moisture-content of standing grain below the danger-level, although grain does occasionally sprout, even in the standing crop, if harvest operations are delayed. In lodged corn or in sheaves, conditions, however, are much more dangerous, as the critical moisture-level is very easily reached and maintained in wet weather owing to the inferior drainage and aeration as compared with standing corn.

Discussion

The results have confirmed that wheat varieties differ widely in their rate of maturation, and that the results of germination tests on dormant grain are considerably influenced by temperature. Figs. 1 and 2 point to an extension of these findings in that they show clearly that differentiation between varieties is far more marked at 23° C. than at 15° C. Thus at the higher temperature the wheats under examination fall into at least two distinct groups, a fact less evident from the results obtained at 15° C. It would seem, therefore, that if laboratory germination tests are to be used for the estimation of sprout-resistance the choice of temperature is of great importance and that a relatively high temperature is essential for satisfactory sensitivity in testing. There remains, however, the question of the justification of the choice of so high a temperature as 23° C. in obtaining a measure of the behaviour of wheat in the field.

In so far as a limited trial is acceptable, the results of ear-germination

tests made under field conditions are far more closely correlated with laboratory tests at 23° C. than at 15° C. This is particularly striking with Yeoman, which germinated poorly both in ear-tests in the field and in laboratory tests at 23° C., although growing freely in laboratory tests at 15° C. The hybrids of the 298 series and 218/37B were somewhat similar in behaviour but germinated less freely than Yeoman at 15° C. Although it would be unsafe to press this too far without further evidence over several seasons and without more information as to the mechanism of dormancy in wheat, it does point to the possibility of making use of standardized laboratory tests as a method of estimating differences in sprout-resistance.

A further aspect of the ear-tests is that the unsprouted damp grain threshed out at the conclusion of testing showed varietal differences in behaviour after storage. Thus, although moisture tests made on grain drawn from the first test indicated a moisture-level sufficiently high to permit of sprouting, some varieties readily sprouted within 24 hours without additional water, whilst others did not. In this connexion Yeoman and the hybrids of the 298 series, amongst others, germinated within 24 hours after removal from the ear, whilst grain from Jubilegem and the highly dormant Atle, Hen Gymro, and April Bearded failed to do so. In the later series similar differences were observed between unsprouted Jubilegem grains and the still dormant wheats Atle, &c., mentioned above. If it be assumed that dormancy in wheat is to some extent a product of the restrictive influence of the seed-coat in the supply of oxygen and water to the embryo, it would seem legitimate to explain the ear-effects noted above as an additional restriction, comparable in magnitude to that induced by increase of temperature on the germination of dormant wheat. That such a restrictive influence is present in ears of unripe grain is demonstrated by the fact that in the milk-stage of ripening the moisture-content of the grain exceeds 50 per cent. In this case germination will sometimes occur in the threshed-out grain but does not appear to occur in the ear except by mechanical injury, which presumably facilitates gaseous exchange and possibly stimulation.

It would appear that laboratory germination tests of unripe grain are unlikely to yield information on sprout-resistance. The behaviour of grain at the fully ripe stage and during the next 2–3 weeks is sufficient to determine the rate of maturation. In the present series of experiments it has been noted that the germinative energy of all the wheats tested rose continuously with time, save for a few minor fluctuations probably due to secondary effects; the pronounced initial fall and subsequent rise in germinative energy described by Bishop [10], and also by Freistedt [11], in their experiments with barley has in no case been observed. The implication of these experiments is therefore that rate of maturation may be measured by laboratory germination tests at 23° C., and that the rate thus measured is related to the tendency of wheat to sprout under field conditions.

Dormancy itself is an ill-defined term, loosely corresponding to lack of maturation. Full maturation is usually accepted to mean that condition

attained by seeds following ripening whereby they are capable of rapid germination given suitable conditions of aeration, temperature, and moisture. Apparently, in wheat, a whole range of temperature from about 7° to 26° C. is suitable for the earliest stages of germination, but in the cases examined the grain is unable to germinate rapidly at the higher temperatures until fully mature, although before this it is capable of normal germination at the lower temperatures. Thus grain showing normal behaviour at the lower temperatures may exhibit marked dormancy at 23° C., and is thus said to be not fully mature. Fully mature grain of high vitality and germinative energy germinates at a rate chiefly dependent upon the temperature rather than upon variety. Differences between fully mature varieties appear to be relatively small compared with the delays introduced by dormancy. Dormant grain takes much longer to germinate, the period of delay being an expression of the degree of dormancy at that temperature, and it may vary from a few hours in mild cases to several weeks in others. During the process of maturation promoted by dry storage, the dormancy, as detected by germination tests, disappears first in the low temperature tests, but the upper temperature at which the germination rate is normal increases gradually with maturation until no dormancy whatever is shown at any temperature consistent with normal germination. It may well be that even grain apparently fully mature at 23° C. would show pronounced dormancy at (say) 27° C., although so high a temperature may introduce a further complication—the possibility of heat damage. Nevertheless, although 23° C. appears to be a much more suitable temperature for the testing of sprout-resistance than 15° C., it is not necessarily the optimum temperature.

The effect of the ear in the particular season chosen (1946) in restricting ease of germination at field temperatures appears to facilitate, or stimulate, the action of some latent factor within the grain itself, rather than to introduce some new factor absent in the grain and present only in the ear. Thus in pot-tests of the threshed grain at similar field temperature the factor is frequently not apparent, yet appears to be as well marked at 23° C. as in the field ear-tests at 15° C. It is, however, impossible to rule out an independent ear-factor entirely until a quantitative correlation has been established, independent of season, between resistance in the field in the ear and laboratory germination tests at 23° C. or other suitable high temperature.

The absence of any true measure of the degree of maturation or of dormancy leaves much to be desired, and the data upon which this report is based have been used to give a numerical value to the degree of maturation at any one temperature, fully mature grain being taken as unity. The values obtained are much lower at 23° C. than at 15° C., and do correspond qualitatively with the degree of sprout-resistance shown in the ear-tests. If similar data were available over the whole temperature-range, it would be possible to assign a figure to any one sample which should indicate its real degree of maturation and its distance from full maturity. The method would be applicable not only to laboratory germination tests but also to ear-tests if a suitable

standardized ear-testing technique were available. It is hoped to collect data of this type in the forthcoming season.

Summary

1. Methods of testing the dormancy of wheat at harvest have been studied.

2. Wheat varieties have been found to vary considerably in the extent to which they show dormancy, at similar stages of ripeness, and in the length of their post-harvest maturation periods.

3. Germination tests at 15° C. and 23° C. have shown that differences between varieties are more clearly defined at 23° C. than at 15° C.

4. Field tests on the germination of grain in the ear have shown a similarity in result with the laboratory tests made at 23° C.

5. Observation has shown that the ear exerts a restrictive influence on the germination of the grain.

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COLONIAL LAND-TENURE RESEARCH

V. LIVERSAGE

WHERE indigenous colonial peoples are concerned most colonial administrations are faced with the inevitability of arriving at some decision as to the form which land-tenure systems should take. The gravest consequences for the future economic and social development of the colonies hinge on the nature of the decision, which cannot be evaded or long postponed. A policy of drift would in itself constitute a definitive decision, as the position is changing with extreme rapidity. The results of protracted research would be obsolete before they were arrived at, as in the meantime a new structure would have crystallized out.

Land-tenure systems are merely one manifestation of the general social organization. They reflect the ways of life of the population, their general outlook, their political and legal systems, and the physical facts of the environment. Many centuries ago the social system among the tribes of Europe seems to have been strangely akin to that existing to-day among many of the more primitive peoples. The language of ancient European law, as of existing custom in the colonies, is concerned with occupation and use of land by right of first arrival, first hunting, first clearing of the forest or conquest, of personal status (as contrasted with contractual rights), of tribes, septs, and family groups, composite families, agnatic relationships, and seigneurial authority. It is tempting to regard primitive societies where still uninfluenced by European contact as in much the same stage of civilization as the prehistoric tribes of Europe.

Our own rural history is still further paralleled by the imposition of feudal elements on tribal systems. Just as in Europe in times of poor communications, weak central governments, and general lawlessness, it was politic to commend oneself to the protection of a strong man, so under similar conditions in Africa and elsewhere feudal hierarchies arose. Land rights were conferred by chiefs in return for military service; tributes of produce and labour services were exacted from the commoners. In many parts of the colonies feudal institutions form the foundation of the land systems to-day.

It may help to give a homely general outline of the way in which the rural system works in those considerable areas where the primitive tribal system still persists, perforce neglecting the many variations and exceptions found in practice and taking an agricultural tribe in east or southern Africa as a type. Imagine, then, an unfenced tract of country, perhaps constituting a single ridge, inhabited by a tribal group who trace their occupation rights from some remote ancestor who arrived there when the land was otherwise uninhabited, or took it in fair fight from the former holder. The boundaries of the land claim of the group will be known to all the members and those of neighbouring tribes. The original claim has, of course, been divided and subdivided by inheritance among the descendants of the original claimant. A process of fission

into family sub-groups is continually going on and the family land claims become intermixed and more or less fragmented. The only fenced portions are small hut and livestock enclosures. Each male member of a family, on attaining manhood, has the right to a portion of land for cultivation. If he does not inherit sufficient he will break up a fresh portion, with the consent of the family head or chief. He might take a small patch or a larger one, depending on his own energy and acquisitiveness and on the resources available for working it (i.e. the number and physical strength of his wives, with or without the addition of oxen and plough). The final result is a patchwork of irregularly shaped cultivated plots scattered over the landscape, the remainder of which is in the condition of the 'commons and wastes' of ancient Europe, part grass, part bush, and part forest.

Inheritance of cultivated land follows established customs, which govern also the allotment of land for cultivation among members of the individual family as, for instance, among wives and daughters. Cultivation rights are usually permanent, so long as the land is being actually used. Manuring is not practised, fertility being maintained where possible by the process of 'shifting cultivation'. Uncultivated land is left to go wild and is grazed in common, without any of the 'stinting' which set a limit to overstocking on the medieval English manor. Livestock itself is regarded as family rather than individual property and its disposal is subject to a good deal of 'red tape'.

Thus, under tribal custom, a landholder may be regarded as a tenant of the tribe, having full security of tenure of a portion of land, which is, however, not permanently limited in amount or specifically delineated. His rights concern the usufruct, and do not extend to the outright possession of the land or sale to a person outside the family. Land is not looked upon as negotiable property, and outright sale would involve the consent of the head of the family and all other members whose rights might be affected—in practice all the senior members—and even consultation with the spirits of the ancestors. There are, however, various ways of getting round this difficulty. The usufruct may be sold in perpetuity, after the manner of a leasehold under English law, or the land may be pledged under the redeemable system for an indefinite period, or a tenant-at-will may be admitted, or a stranger may be admitted under the fiction of adoption.

The effect of European colonization has been to project peoples living a quiet, self-sufficient, food-cultivation and cattle-herding existence with dramatic suddenness into the vortex of twentieth-century commercialism. The evolution of 2,000 years in Europe has in their case been compressed into a period of less than half a century. Tribal warfare has given place to the rule of law. A subsistence economy has had an exchange- and money-economy superimposed upon it. Development of transport facilities has brought most parts into contact with internal and foreign markets. The products of home industry no longer suffice for a scale of wants which has suddenly expanded to include European clothes, bicycles, gramophones, and other products of modern large-scale manufacture. Land which sufficed for family needs is inadequate

to produce a surplus to exchange for manufactured goods, meet the need for social services, and pay the costs of administration. Every advance in social betterment brings with it a rise in the average expectation of life of both men and animals. Development of secondary industries does not promise to be rapid enough to prevent an increase in the drain upon the land.

Under the new conditions the old land system breaks down. Not only does increased population press upon the available area for the means of home subsistence, but additional land is broken up for cultivation of sale crops. The margin for shifting cultivation shrinks and finally disappears. The land of the more fecund tribes and families becomes more and more subdivided until cultivation becomes continuous. The rural tradition is generally against any attempt to build up fertility and permanent equipment in the land. Anti-erosion works are not willingly constructed, and so far from organic manures and chemical fertilizers being applied, the arable land is cropped year after year, often twice a year, until exhaustion is complete or the top soil even washed away. The system of irregularly distributed garden-sized patches of unfenced cultivation does not lend itself to the use of livestock to maintain the fertility of the arable land. Cattle, goats, and hair-clad sheep multiply on the dwindling commons, stripping the land bare of vegetation during the dry seasons, and exposing it to the full force of the early rainstorms, leading at the best to domination of the herbage by inferior succession species and at the worst to disastrous gully and sheet erosion. The animals themselves appear to evolve towards a poor unproductive type, able to stay the course by carrying little weight. Common rights to the waste result in destruction of timber and a final resort to cattle manure for fuel.

The colonial peoples are adapting themselves to the new conditions. Rapid changes in land tenure are already in progress, but these are sometimes in directions portending fresh problems in the future. There is a new urge to assert individual land rights, free from family and tribal control, to obtain unencumbered possession of larger areas. There are reports of holdings extending to hundreds of acres put under industrial crops, in areas where dense populations are struggling to feed themselves from soil drying up from lack of humus and going rapidly downhill. There is a growing awareness of land as a form of property, saleable and mortgageable, offering possibilities of quicker returns as a subject of speculation than through conservative agriculture. Prosperous individuals are obtaining land rights by lending money to peasants for cultivation expenses, marriage and other social ceremonies, and payment of tax. Some even discern that by obtaining control of land they can live on the labour of those who use it, by exacting a rack-rent for its use. The search for quick returns at the cost of future impoverishment appears to arouse no misgiving on the part of those engaged in it.

The necessity for a more intensive and conservational style of farming is obvious. Under the existing system of tenure arable holdings are not laid out in a workmanlike manner, and there is no close association of livestock husbandry and arable farming. The individual who ruins one

piece of land can repeat the process on another and the consequences of his depredations fall on the community at large instead of on him individually. The conception of soil fertility and permanent equipment in land as a personal asset has not yet taken root. Whilst the public interest is to reduce overstocking of the common pastures, the individual's is to own as large numbers of livestock as possible. 'When it is everybody's interest to improve the pastures it is nobody's interest to do the work.' An even more difficult task which must be undertaken is to halt the process of drawing on capital in the shape of soil fertility for the purpose of maintaining an increasingly dense population at a rising standard of living. All are not agreed that greater individual responsibility will induce a change of attitude; some believe that the solution lies in more conscious collective responsibility, applied with more directive force, even if the direction should have to come from outside the native community.

Over a large part of the world, including many of the colonial areas, the primitive tribal system either never existed or has evolved into different forms. A wide variety of tenure systems and modifications exists to-day. What lessons are to be learned from the past history and contemporary economic results of these systems under various conditions? This is the first step towards a sound judgement as to the best objective in the colonies. Some time ago there was a disposition to accept as axiomatic that peasant proprietorship was the highest and most desirable aim. Belief in Arthur Young's 'magic of property' has lately become somewhat shaken and attention has been turned in other directions. Means of prevention of misuse of land are being sought and some measure of public control is often advocated. The possibilities of dual or tripartite developments as employed on the Gezira plantation in the Sudan are being examined, and there is speculation as to whether the groundnut-growing scheme recently initiated in East Africa can be modified to serve the needs of African social life as well as economic development. Thought along such lines has been stimulated by the realization, brought into sharp relief in connexion with plans for the utilization of the Colonial Development and Welfare Vote, of the miserably low standard of life which is general under peasant agriculture in the British colonies, as indeed in many other parts of the world. Can the position be eased by application of capital and increase in production per man, or would the effect simply be to leave manpower unemployed and occasion a net loss represented by the service of the capital?

Unfortunately, action cannot wait on long-range research. If something is not done soon a rural revolution in the colonies will have been already consummated, and it appears that it may be a revolution fraught with unfortunate consequences for the future of the inhabitants, whatever it may mean for the rest of the world. Nevertheless, while interim judgements are being acted upon it is of the greatest moment that comparative studies should be undertaken with a view to the evolution of a long-term policy.

Thus, at the one end, it is necessary to decide where we stand on the question of farm-land tenure in the modern world towards which the

colonial peoples are heading. At the other end it is necessary to know more of the nature and origin of the traditional systems, and especially in their light to explore the nebulous border-land between old history and the new order. It would be unfortunate if research were to lose itself in the fascinating by-ways of anthropology, for the present-day problems arise not so much from the nature of the traditional systems as from their supersession under changed conditions. At the same time, a true understanding of the past is necessary for the formation of sound judgements on the present and future. The description given above is the merest general outline. Each locality has its own variants, has followed its own path of evolution, and has reached its own particular stage on the way. It is necessary to know in concrete terms what direction is being taken in each community, what stage has been reached, what is the pace of travel, and what have been the observable effects so far. On the information so obtained must depend the answer to the practical question as to whether any intervention is advisable, what degree of urgency exists, and what must be the mechanics of intervention. It is impossible to wipe the slate clean and start again. The new picture must be superimposed on the old. A few valuable studies have been made so far, the majority leaning somewhat towards the socio-legal aspect of the traditional systems. Many more field studies of an intensive nature are desirable, made against a background of general anthropology, but dealing more closely with the actual mechanics of social systems in so far as they affect land utilization. We need to know where control over possession or use of land resides, in what directions it is actually exercised, what is the actual state of land (and livestock) distribution at the present time, how and at what pace it is changing, what results are actually obtained from land utilization, what (if any) contingent rights limit an individual's power or inclination to develop the land fully, protect it adequately, or invest his capital in labour or other forms in it. We need to know much more of the precise way in which the system works. How, for instance, in a polygamous family is the cultivated land allotted to the wives and inherited by the daughters? Is fragmentation by this or other means a serious problem? What obstacles does the system present to the adoption of modern methods? In some tribes there is, or has been in the past, some form of control of grazing of the uncultivated land. Is this practice more widespread than we have suspected, and is it capable of being turned to use in overstocked areas to-day? The skeleton of the whole subject is as yet seen only in dim outline; it needs the addition of fleshy organs, clothes, and ornaments as well to be truly realistic. Unfortunately, in gathering the details an intense degree of suspicion on the part of the native inhabitants will be met with, and evidence, to be reliable, must be mainly indirect.

It is necessary, of course, to distinguish between coexistence and causation; to avoid ascribing the apparent defects of colonial agriculture under contemporary conditions entirely to unsuitable tenure systems or expecting that tenure reform will of itself result in the adoption of improved methods. Something more fundamental is involved. The genius of the people may produce widely differing results from a similar tenure

system, as we see with cash tenancy in England and the United States, or peasant proprietorship in Ireland and India; broadly similar results may be obtained from different systems, as cash tenancy in Great Britain and peasant proprietorship in Northern Ireland. The fundamental factor is the outlook of the farmer and landowner. The tenure system is more often an expression of agricultural methods and outlook than vice versa. However, a revolution in agricultural methods cannot be brought about without the creation of the right conditions; if we would initiate new systems of farming we must develop institutions under which they can come into being and survive.

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THE USE OF SEED FROM DIFFERENT PICKINGS OF THE COTTON CROP

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Introductory.—Literature on this aspect of the cotton crop is very scanty indeed. It can, however, be surmised that, as the cotton plant remains in the reproductive phase for several months, the seed obtained in the different pickings is subject to a changing intensity of environmental factors and might exhibit in some way the impact of these changes in the environment [1].

American varieties of cotton (*Gossypium hirsutum* Linn.) start flowering at Lyallpur early in August. Most of the flowers produced during August and early September are shed on account of non-dehiscence of the anthers [2]. The first picking is taken in mid-October and the crop is finished in three or four pickings by the end of January. The local varieties (*G. arboreum* Linn. var. *neglectum* forma *bengalensis* Hutchinson and Ghose) start flowering from the end of July, and also shed their early flowers; not in this case because of non-dehiscence of anthers but as a direct result of severe heat and low humidity. The first picking is in mid-September and the crop is finished, in about eight fortnightly pickings, by the end of December.

In ecological relationship to the cotton crop the climate of Lyallpur can be termed severe. The whole climatic phase of Lyallpur has already been described in detail [3, 4], and it will suffice to state here that the climate becomes steadily milder with the onset of flowering and really cold in December. There is a general expectation of frost during Christmas week and the temperature reaches the freezing-point practically every night during January. Thus the early and late flowers and bolls of the cotton plant develop under entirely different sets of environmental conditions and so may show the effect of these in some way. The present work was undertaken to explore these possible effects. The purely economic property of yield, being the most important, was the first to be studied.

The local Department of Agriculture has been advocating the use of seed from the middle pickings for sowing. A thorough inquiry into the genesis of this recommendation has been fruitless and it appears that in making it reliance was placed, not on experimental evidence, but on folk-lore. The only other reference we have been able to trace is to the Egyptian experiments [5] on the use of seed from the first or second picking. In Egypt only two pickings of the cotton crop are taken. It has been stated that '*a priori* reasoning would suggest that except when dealing with absolutely pure seed, continuous use of second-picking seed, as compared with the selection of first-picking seed only for *taqavi* (sowing), must have a cumulative effect, and if continued over a very large number of years in a progressive scheme of bulk propagation,

would be certain to produce a later maturity in the type. More definite objections are also raised by cultivators, on the grounds of experience, that the crop is both less in quantity and inferior in quality.' Experiments were, therefore, carried out with Sakel at two places and the following conclusions were drawn:

(1) The total yield is not reduced when second-picking seed is used for sowing.
(2) The amount of first-picking in the crop may be reduced slightly, but this is probably only a secondary effect resulting from the amount of re-sowing necessary, and would be most likely overcome by an increased sowing-rate.
(3) An increase in the sowing-rate is recommended for second-picking seed used as *taqavi*; the increase to be inversely proportional to the germinating capacity of the seed.
(4) Earliness in maturity, class, and quality are likely to be maintained.
(5) Second-picking seed may be safely used during the early years of propagation of pure or superior varieties and strains.

Experimental technique.—During 1944 bulk-plots of two pure American varieties (L.S.S. and 289F/43) and of one local variety (39 Mollisoni) were picked separately for each picking. There were three pickings of L.S.S., four of 289F/43, and eight of 39 Mollisoni. The produce from each picking was ginned separately, and during 1945 the seed of different pickings was sown in randomized blocks just like varietal test-plots. The size of beds and the number of replications in each variety are given in Table 1.

TABLE 1. *Arrangement of Plots in the First Year (Y1), 1945–6*

Varieties	*Pickings*	*Bed-size (feet)*	*Replications*
289F/43 . .	4	150×18	5
L.S.S. . .	3	144×18	7
39 Mollisoni .	8	150×18	4

The pickings were made during the winter of 1945–6 and were again kept separate. During this year there were four pickings both of 289F/43 and L.S.S. and eight of 39 Mollisoni. The produce was ginned separately as in the previous year and the seed so obtained was sown in May 1946 in randomized 'family' blocks. The arrangement of plots during this year is shown in Table 2.

TABLE 2. *Arrangement of Plots in the Second Year (Y2), 1946–7*

Varieties	*Pickings*		*Treatments*	*Bed-size (feet)*	*Replications*
	Y 1	*Y 2*			
289F/43 . .	4	4	16	78×10	6
L.S.S. . .	3	4	12	75×12·5	6
39 Mollisoni .	8	8	64	54×7·5	3

It is thus possible to study the cumulative effect on yield of the seed from different pickings.

Germination.—The percentage of field germination was studied during both years and the figures for the first year are given in Table 3.

TABLE 3. *Field Germination during the First Year (Y1), 1945–6*

Variety	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*d1*
289F/43 .	22·34	27·87	28·24	33·18	..	..	..	..	± 1·77
L.S.S. .	34·11	25·76	25·62	..	..	..	..	..	± 2·30
39 Mollisoni	58·03	61·12	63·08	56·02	55·79	55·25	52·33	35·38	±13·12

d1 = Critical difference at 5 per cent. level.

Table 3 shows that the American varieties had on the whole a lower germinating capacity than the local variety; also that the germination percentage of seeds from different pickings varied significantly (at 5 per cent. level) in all the varieties, but the order of the different pickings was not the same. In 289F/43 the seed from the last two pickings gave a very much higher germination percentage, but the reverse occurred in L.S.S. and 39 Mollisoni.

The germination percentages in the second year were as follows (Table 4):

TABLE 4. *Field Germination during the Second Year (Y2), 1946–7*

Variety and picks of Y1		*Pickings of Y2*								*d1*
		P1	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	
289F/43:	P1	62·2	58·2	52·2	14·1	..	..	..	..	±10·21
	P2	54·4	56·9	62·7	21·1	..	..	..	..	± 9·29
	P3	20·8	59·2	54·6	45·1	..	..	..	..	± 2·31
	P4	18·1	53·9	57·5	46·8	..	..	..	..	± 7·84
L.S.S.:	P1	73·3	77·1	77·1	55·3	..	..	..	..	± 7·06
	P2	68·6	71·7	66·3	54·8	..	..	..	..	± 8·67
	P3	76·3	75·9	70·5	53·9	..	..	..	..	± 8·88
39 Mollisoni:	P1	45·9	58·3	47·4	55·4	55·1	69·2	56·6	50·2	± 9·42
	P2	43·1	48·1	54·1	57·4	48·6	58·0	45·1	51·4	±11·26
	P3	45·5	59·0	62·9	52·4	60·7	54·4	59·0	45·6	±11·54
	P4	47·5	53·7	50·5	60·9	61·2	55·5	54·6	44·6	±10·66
	P5	47·8	57·9	54·2	47·8	65·1	52·3	55·2	35·5	±11·45
	P6	53·7	56·5	49·5	50·6	52·0	51·3	50·0	38·5	±13·75
	P7	42·8	72·2	59·5	53·5	54·4	63·5	53·5	40·3	±10·84
	P8	52·2	43·4	55·4	50·4	51·4	50·4	54·9	60·0	±17·14

The data given in Table 4 are of interest and particularly those for 289F/43. In the first two pickings of Y1 the germination percentage in Y2 was much better in the first three pickings and very low in the fourth picking. In the third and fourth picking of Y1, the germination percentage in Y2 was very bad in the first picking and was good in the last three pickings. No suitable explanation can be offered at this stage for this reversal of results. In L.S.S. the last picking generally gave a lower germination percentage than the first three pickings. In 39 Mollisoni it was generally found that the early and late pickings gave seed with lower germination capacity. In this case there was little to choose in the different pickings of Y1.

The germination capacity of seeds from different pickings may now be summarized. In any case where the seed from either the early or the late pickings is to be used, it would be safe to advocate a higher seed-rate than is generally employed. Cotton seed is a fairly cheap commodity, selling at about Rs. 10 per maund (less than £1 per 100 lb.), and the usual seed-rate employed in the Punjab is 5 to 8 seers (1 maund=40 seers) per acre. A few more seers of seed per acre will be a very good insurance for a proper stand of the crop.

Yields.—As the investigation was carried out through two successive years, it will be best to discuss the results in two stages. In these tests a very high seed-rate was used in order to procure a uniformly good stand in all the beds. The stand was therefore uniform and any difference in yield can, with ample justification, be ascribed to the different pickings from which the seed was obtained. In the final analysis of results the yield was adjusted to the stand and in the Tables that follow only the adjusted yield is given. The differences in yield are thus solely due to the pickings.

During 1945–6 (Y1), the difference in the yield was not significant (Table 5).

TABLE 5. *Adjusted Yields of Different Varieties, 1945–6 (Y1)*

Varieties	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*Remarks*
289F/43 .	11·97	12·22	12·55	13·04	..	..	..	..	N.S.
L.S.S. .	15·02	15·34	15·06	..	..	..	..	..	
39 Mollisoni	12·32	12·44	11·59	12·28	11·71	12·05	12·50	12·11	

The figures given in this Table lead to the conclusion that the seed from any picking may be used with impunity, providing of course that the stand is uniform.

The cumulative effect of using seed from different pickings for sowing should be shown by the results of the second year, 1946–7 (Y2). The analysis of variance of the results of this year was carried out in two stages, namely, for the main pickings of 1944–5 and the subsidiary pickings of 1945–6. These results are discussed below separately for each variety.

289F/43.—As stated above, the plots in 1946–7 were sown in randomized 'family' blocks, the original pickings of 1944–5 representing the 'families'.

The results of the analysis of variance for the original pickings were not significant and the yields obtained were:

	1st pick	*2nd pick*	*3rd pick*	*4th pick*
Maunds per acre . .	12·06	12·35	11·53	12·10

The analysis of variance for the subsidiary pickings done during 1945–6 was then carried out and the adjusted yields are given in Table 6.

Thus the results were not significant in three cases out of four. A comparison of Table 6 with Table 5 brings out an interesting point, viz. that in 289F/43 the use of seed from the last picking resulted in a some-

what higher yield. Although the results must, on the whole, be considered not significant, the use of seed from the last picking may yield a slightly higher income per acre than would be the case if the seed from

TABLE 6. *Yield in Maunds per Acre in Y2*

Pick no. in Y1	*Pick no. in Y2*				*d1*
	P1	*P2*	*P3*	*P4*	
P1	11·1	13·1	10·7	13·7	± 1·69
P2	11·9	12·0	12·2	13·3	N.S.
P3	10·7	11·6	11·5	12·4	N.S.
P4	11·6	11·5	12·2	12·2	N.S.

the main pickings were used. This point, however, needs further confirmation.

L.S.S.—Here again it was found that the difference in yield from the main pickings of 1944–5 was non-significant, the figures being:

	1st pick	*2nd pick*	*3rd pick*
Maunds per acre . .	13·34	14·45	13·71

As the crop from each of these three pickings had given four pickings during 1945–6, the adjusted yield of each of these is given in Table 7.

TABLE 7. *Yield in Maunds per Acre in Y2*

Pick no. in Y1	*Pick no. in Y2*				*d1*
	P1	*P2*	*P3*	*P4*	
P1	14·02	13·50	13·20	12·50	N.S.
P2	14·60	14·40	14·40	14·50	N.S.
P3	14·40	14·00	13·30	13·50	N.S.

The results in both years (cf. Table 5) were not significant, and it may therefore be stated in general terms that L.S.S. seed from any picking may be used for next year's sowing.

39 Mollisoni.—The analysis of variance of the main pickings once again showed that the results were not significant. The adjusted yields in maunds per acre were:

1st pick	*2nd pick*	*3rd pick*	*4th pick*	*5th pick*	*6th pick*	*7th pick*	*8th pick*
21·6	18·4	22·4	22·7	17·9	20·1	22·7	18·1

The analysis of variance of the second order was carried out and the adjusted yields are shown in Table 8.

Table 8 shows that only two of the results were significant, but when these results are considered in conjunction with those for 39 Mollisoni

given in Table 5, it may be safely assumed that the seed from any picking may be used with impunity.

All these results have shown that there was no cumulative effect on yield of using seed from a particular picking for two successive years,

TABLE 8. *Yield in Maunds per Acre*

Pick no. in Y1	*Pick no. in Y2*								
	P1	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*d1*
1	24·2	23·8	21·9	23·3	20·0	22·9	21·9	20·4	N.S.
2	18·6	20·0	19·1	17·5	17·7	18·1	19·4	20·4	N.S.
3	20·1	21·6	21·0	21·4	21·7	24·2	20·5	23·0	±2·86
4	22·4	22·4	21·1	22·3	22·4	22·3	23·4	22·8	N.S.
5	18·2	16·7	16·1	18·7	17·1	17·8	18·5	17·8	N.S.
6	17·8	21·0	20·6	19·1	20·0	18·4	20·0	19·2	N.S.
7	21·3	22·4	20·8	24·5	25·5	22·7	22·2	21·5	±2·29
8	17·2	18·8	19·0	18·6	18·5	19·2	16·6	20·1	N.S.

so that the plant-breeder and the farmer have a free choice of seed from any picking.

The Egyptian workers (loc. cit.) have alluded to the introduction of lateness by the continuous use of seed from the second picking. This point was also investigated and the co-efficient of earliness of the crop was calculated during both years for the crop gathered from the seed of each picking. For working out this co-efficient the following formula was used:

$$\text{Co-efficient of earliness} = \frac{Y1}{T} + \frac{Y1+Y2}{T} + \frac{Y1+Y2+Y3}{T} + \frac{Y1+\ldots Yn}{T} + \frac{T}{T}.$$

Where Y1 + Y2, &c., denote the yield obtained in the first, second, and *n*th picking and *T* the total final yield. These data for the two years are given in Tables 9 and 10.

TABLE 9. *Co-efficients of Earliness during the First Year*

Pickings	*289F/43*	*L.S.S.*	*39 Mollisoni*
1	3·04	2·86	5·78
2	3·07	2·72	5·53
3	3·02	2·73	5·77
4	3·11	..	5·79
5	..	..	5·82
6	..	..	5·86
7	..	..	5·85
8	..	..	6·06

Tables 9 and 10 show that the earliness of the crop was not at all affected by the continuous use of seed from early or late pickings and that, in the Punjab, the seed from any picking may be used without affecting the earliness of the succeeding crop.

Discussion

The cotton trade in India recognizes only three conventional 'pickings', the first, second, and third, representing the very early crop, the

TABLE 10. *Co-efficients of Earliness during the Second Year*

Pickings in Y2	*Pickings during the first year (Y1)*															
	289F/43				*L.S.S.*			*39 Mollisoni*								
	1	*2*	*3*	*4*	*1*	*2*	*3*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	2·44	2·28	2·21	2·19	1·92	1·89	1·89	4·76	4·77	4·83	4·81	4·64	4·70	4·64	4·63
2	2·37	2·30	2·22	2·23	1·89	1·87	1·88	4·94	4·80	4·73	4·83	4·55	4·64	4·73	4·69
3	2·33	2·21	2·28	2·25	1·90	1·85	1·87	4·95	4·82	4·65	4·92	4·59	4·62	4·71	4·76
4	2·30	2·27	2·32	2·31	1·89	1·86	1·83	4·78	4·78	4·73	4·87	4·56	4·80	4·72	4·66
5	..	..	..	..	..	..	..	4·74	4·68	4·80	4·85	4·62	4·69	4·67	4·82
6	..	..	..	..	..	..	..	4·72	4·72	4·85	4·90	4·71	4·84	4·64	4·71
7	..	..	..	..	..	..	..	4·62	4·87	4·73	4·87	4·65	4·78	4·51	4·54
8	..	..	..	..	..	..	..	4·93	4·82	4·58	4·91	4·53	4·69	4·67	4·79

bulk of the crop, and the very late crop, respectively. The first and the third pickings always sell at a discount [6]. Up to now the farmers have been encouraged to keep seed from the middle pickings for sowing, and they had therefore to keep some seed-cotton from this portion of the crop for home ginning and preserving the seed. This practice appears to be uneconomical and the present results have shown that farmers would be well advised to sell the high-priced *Kapas* (seed-cotton) from the main pickings and keep only the comparatively low-priced early and late pickings for seed. Thus the net cash return per acre will be greater.

Summary.—The present experiments have shown that neither the yield nor the earliness of the cotton crop suffers in any way by the use of seed from early or late pickings, and that it will be more economical to use this seed for sowing.

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IRRIGATION FROM THE GROUND-WATER FOR STIMULATING FOOD PRODUCTION IN DESERT AREAS

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1. *Introductory.*—In view of the acute scarcity now prevailing in the central and the eastern world little apology is needed for setting forth constructive suggestions, based on recent experience in India, for increasing food production in areas where (*a*) an erratic and deficient rainfall justifies irrigation, and/or (*b*) the geological conditions permit of the adoption of the special methods described briefly below. The alternative of importing millions of tons of food grains from the western plains to meet the world deficits, entailing as it does a prodigious ton-mileage of shipping, apart from heavy inroads on the already depleted dollar reserves of importing countries, will, it is believed, be shortly precluded by the exhaustion of these assets. Either, therefore, local production must be stimulated or millions must starve—or have their health and happiness ruined by malnutrition. The methods here proposed for certain areas have recently been proved in parts of India—notably in the western plain of the Ganges where systematic irrigation from ground-water sources has been established in a few years to the extent of more than a million acres. They have, moreover, been developed in California and in parts of Arizona, which the writer visited on two recent occasions. It is possible that a similar technique can be successfully adopted in other scarcity regions where vast areas of riparian alluvium may exist, e.g. the lower Nile valley, parts of north Africa, and the riverain plains of east and south Africa. Whilst, therefore, this review does not suggest that tube-wells are necessarily feasible under African and near-eastern conditions it does indicate that a prima-facie case exists for a thorough investigation of potentialities for applying a technique which has proved successful in northern India.

2. *Construction versus criticism.*—In anticipation of criticism that may be directed against these proposals the following relevant facts are quoted. When the initial Ganges Valley Hydro-electric Tube-well project was almost completed on the eve of his retirement as Chief Engineer in 1937, the writer was asked at what cost the capital losses could be cut and the scheme shut down, so intense was the public criticism of the enterprise. This criticism was based partly on the doubts expressed as to the ultimate effect of pumping on the subsoil supplies and partly on local distrust of a technique hitherto untried on the vast scale then contemplated. Persuasion and inherent good sense, however, prevailed and the 'million-acre scheme' was completed—albeit with some local misgiving. The sequel is interesting. During the budget debate of 1939 in the U.P. Assembly the Premier paid tribute to the tube-wells which, he declared, had saved the western areas of his province from the scarcity which had ravished the adjoining districts of an adjacent province owing to the partial failure of the 1938 monsoon! With this

justification the Government put forward a demand for 100 additional tube-wells which was readily voted. It is understood that the system is now being extended to those central and eastern areas of the province where irrigation from river-sources was deemed uneconomic. The fact, too, that the so-called Interim Government of India, enthusiastically backed by a Congress opposition, sanctioned in 1946 a costly organization for demonstrating the efficacy of tube-wells for increasing food production in other parts of India, indicates that the public are now tube-well conscious. During a two-months' air-inspection with the writer, a number of local projects were reviewed last year by an eminent American consultant; these are now to be carried out in various parts of the alluvial plains extending from western Bengal to the Arabian Sea. Too much importance cannot, it is felt, be attached to the view of this engineer, Mr. Roscoe Moss of Los Angeles, whose firm has constructed some 4,000 large irrigation tube-wells in the Western States. His report, in fact, like the Atlantic Charter, offers 'Freedom from want' to millions of peasants living at present on the margin of starvation.

3. *Value of irrigation.*—Ideally, irrigation, accompanied when necessary by artificial fertilization, should be so regulated as to make up the difference between the moisture needed to secure an optimum yield and the actual rainfall on the area in question. In India where the monsoon is usually erratic, and sometimes (perhaps 1 year in 5 or 6) fails completely, the increased yield attributable to systematic irrigation can be assessed at an average of 60 to 100 per cent., or, in other words, on an irrigated acre $\frac{1}{2}$–$\frac{1}{3}$ ton of wheat would be yielded against, say, $\frac{1}{4}$–$\frac{1}{5}$ ton on a 'dry' field. In the west of India, for instance, i.e. within the zones of the lower rainfall contours (5–15 in., falling almost entirely during July–September), irrigation is essential to the mere sowing, let alone the efficient maturing of crops. Irrigation in these regions, especially if accompanied by the proper application of fertilizers (cow-dung humus plus chemicals if available), will more than double the yield of such catch crops as can be sown during spasmodic showers, apart from the insurance it affords against total loss in years of monsoon failure. This argument applies, *mutatis mutandis*, with equal relevance to agricultural production in the other countries referred to above.

One more point in favour of so-called 'mechanical irrigation' (see para. 5) must be quoted. Apart from its direct agricultural value, irrigation pumping (from both wells and deep-flowing rivers) furnishes the 'base load' required to justify the installation of a widespread power system, thereby enabling low-cost energy to be introduced into rural areas where, otherwise, the cost of generating power might well prove sub-economic.

4. *Sources of irrigation.*—Prior to the spread of mechanically driven tube-wells in parts of India, irrigation was normally effected from two main sources: (*a*) from open wells, operated by animal or manual power, in 'dry' (or non-canal) areas; (*b*) from the great river–canal systems which in India alone protect more than 50 million acres of otherwise precarious crops. Dealing briefly with these systems: (*a*) well-irrigation is relatively expensive in operation and, further, imposes a severe drain on the man- and cattle-power of the villages. If such drain can be avoided the

agencies thus released can be utilized for more profitable and, in the case of men, less soul-destroying activities. Figures can be readily quoted to show that tube-well irrigation, whilst usually slightly more expensive per acre[1] than from canals, is definitely cheaper than the mere sprinkling normally provided from open wells. (*b*) Irrigation is ideally effected both in India and elsewhere by gravity 'flow' from the river-fed canal systems. Unfortunately, however, most of the water of the main rivers of India has already been allocated to existing canals and thus expansion can be secured only by the expensive (and, sometimes, technically difficult) method of retaining surplus monsoon-water in storage reservoirs to be projected in the mountain catchments of the parent rivers. Further, as the writer recently pointed out in an address[2] to the Indian Institution of Engineers, apart from the high capital cost, the time incurred in constructing the dams, diversions, and ancillary works comprising a major canal system is likely to debar such schemes from rendering an early solution to the immediate food problem. For instance, in the case of northern India, it is probable that the major storage reservoirs now being projected will not contribute materially to the food-supply before 1960. How many millions must die of hunger or wilt from malnutrition before these highly necessary measures can be fully effective?

5. *Power-operated tube-wells—general.*—Before discussing the potentialities for irrigation expansion elsewhere, it would clarify the issue to describe briefly what was achieved in the United Provinces, India, during the period 1934–7, when about three-quarters of a million acres were brought under systematic irrigation by means of sinking some 1,700 tube-wells in seven western districts of the province. The tubes were sunk to an average depth of 270 ft., thus tapping an aggregate of 80 ft. of coarse water-laden sands (aquifers), and each yielding about 30,000 gallons per hour, with a total lift of 40–50 ft., including an average depth to the water-table of about 20 ft. The pumps are driven from the Ganges Canal Hydro-electric Grid System, which derives its energy from a series of falls on the main canal. Apart from the pumping load, power is also supplied to a large number of cities, small towns, and villages as well as river pumping stations which lift drainage water from low to high levels so as to command local tracts of cultivation. The volume pumped for irrigation exceeds half the cold weather flow of the Ganges at the canal headworks (some 6,000 cusecs). No appreciable decline in the permanent water-table of the plain has so far been detected.

Each tube-well, which 'commands' an area of roughly 1,000 acres on the average, irrigates 500 acres of crops in the year, to the requisite depth for maturing wheat, fodder, cotton, and sugar-cane. Double cropping of the commanded area (some 2 million acres) is, moreover, thereby secured.

[1] Tube-well water is sold volumetrically. Hence the cultivators can irrigate more economically in periods when casual rainfall occurs. The average cost of watering an acre of wheat is about 6 rupees for 2½ waterings of 5 in., against 5/- for flow irrigation (flat rate per acre).

[2] See 'Planning for Plenty', read before the Institution of Engineers, India, Nov. 1944.

Another important feature of the tube-well is the amenities afforded for better hygienic conditions, e.g. pure drinking-water for villagers and cattle, bathing-pools, washing facilities, &c. Cholera, typhoid, and other intestinal diseases have, as a result, greatly diminished.

6. *Source of tube-well water—'the hidden river'*.—At this stage the question may well be asked, 'Where does all this water come from and why does not widespread desiccation of the country-side result from its withdrawal?' A reference to two lectures[1] to the East India Association on 'The Himalayan Dream' (on Dec. 17, 1946), and 'Planning against Poverty' (Sept. 27, 1945) is given in answer. It was explained that, seeping through the coarser strata[2] underlying the great plain of the Ganges (and to a lesser extent, too, below the vast Indus basin draining the Punjab, Sind, and adjoining States) there exists a 'hidden river' (the *Saraswati* of Hindu mythology) which, whilst moving very slowly, its speed depending on the gradient of the plain, furnishes an abundant supply of pure water for the tubes that might, and should be, sunk to lift it on to the lands above.

The tube-wells of the western Ganges system in the United Provinces, which, after all, was merely a reconnaissance into the potentialities of a new technique, intercept some 80 ft. aggregate depth out of a total of, perhaps, 3,000 ft. of the alluvial deposits forming the floor of this geological valley. The sources of this hidden stream are obviously of vital importance to projects involving wholesale tapping of the underground supply. Very briefly, they may be outlined as follows:

(i) Rainfall on the tract itself. In the west U.P. this averages 25 in. in the monsoon (July–September) and perhaps 2–3 in. in the cold weather, of which a proportion (it may be 15–20 per cent. depending on the porosity of the soil, the intensity of the fall, and other local features) reaches the permanent water-table.

(ii) Absorption from artificial irrigation, perhaps 20 per cent. of the aggregate 'depth' applied, returns to the subsoil.

(iii) Extraneous contributions from: (*a*) Porous river- and canal-beds flowing within and adjacent to the area itself. (*b*) The more porous zones bordering the sub-montane flanks of the plain, mainly to the north, where, owing to the hills, the rainfall is much greater (80–100 in.) and the intake area more receptive.

When the Ganges Valley Tube-well Scheme was projected in 1934–5, an expert committee was appointed to examine the various sources of the ground-water. In giving the 'line clear' to this aspect of the project, the geologists, whilst basing their calculations mainly on the rainfall, emphasized that the extraneous source, although indeterminate, constituted an important reserve against over-pumping of the local supplies.

Mention should be made, however, of certain factors which may well impose a limit to the possibilities of irrigation from ground-water sources in the lower reaches of the Ganges plain. Whilst due to increasing pres-

[1] See proceedings, *Asiatic Review* for April 1947, **43**, 97–108; also **42** (149), pp. 1–12 (especially pp. 5 and 6).

[2] These water-carrying sands are known to geologists as 'aquifers'.

sure[1] of population on the land the need for systematic irrigation becomes greater, the flow of the Saraswati becomes less and less towards the Bengal delta. This is due to two causes: (*a*) the diminishing slope of the valley, and (*b*) the increasing proportion of finer and, therefore, less porous sands. Thus, were it not for one countervailing factor, the prospects of salvation for cultivators in the lower valley would be grim indeed.

A glance at the map of the eastern U.P. and Bihar will show that, impinging into the main valley from both the northern and southern hills, a series of streams, large and small, brings in their contributions in the form of sub-deltas which constitute important local zones. These can not only be freely tapped for irrigation, but also contribute substantially to the main underground flow.

7. *The Saraswati—quantitative aspect.*—Accurate measurement of the actual flow of the ground-water is precluded by the lack of exact data, especially in regard to the speed of seepage. A rough idea can, however, be got from the following approximation. Taking the average width of the western Ganges alluvium between the Himalayan foot-hills and the Vindhyas as, say, 150 miles, and the mean aggregate depth of the coarse water-bearing strata to be tapped by the strainers of deep tube-wells as 120 ft., the cross-sectional area of the sands thus intercepted would be of the order of 95 million sq. ft. Assuming a porosity of 33 per cent. the effective percolation area may be roughly 32 million sq. ft. The rate of ground-water seepage across this area is largely indeterminate, varying as it does with the gradient of the plain, the size of the sand grains, and other local factors. If, in the upper reaches of the valley, where the gradient is steeper, seepage takes place at a rate of 1 mile per year, the underground flow would be of the order of 5,000 cusecs. Whatever the actual figure may be, it is clear that the Saraswati—reinforced as it undoubtedly is by constant inflow—is an asset of primary importance for raising crops. Although it must be admitted that the subsoil features of the Ganges valley are extremely favourable for exploitation, one cannot but believe, when looking at an Empire map of Africa, that similar hydrological potentialities exist, even if on a smaller scale, below some of the alluvial plains of the great river-basins.

8. *Power for pumping.*—The provision of low-cost power for pumping is obviously an essential requisite in any major scheme of tube-well irrigation. Ideally, power for a widespread system would be developed by stages. In the Ganges valley, for instance, where irrigation costs from the outset were economic, development has proceeded somewhat on the following lines. In the first, or exploratory, stage where the tube-wells are necessarily widely spaced, oil-engines of suitable capacity were installed at the wells. In the second stage, when the yield of a tract had been 'proved', additional wells were sunk in the intervening spaces, the system being intensified into a 'group'. The oil-engines were then replaced by electric motors energized through a local network from a Diesel (or hydro) power station. Thirdly, as the system expanded across the

[1] In many parts of Bihar the intensity of population is 1,000 souls per square mile.

tract under development, a number of groups were combined and supplied from a larger and thus more economical hydro-electric and/or thermal source. Finally, in the sub-montane areas, large-scale hydro-electric power is being developed as a supplement to, or a substitute for, the hydro-thermal stations. Thus by a process of systematic expansion mountain power is brought economically to the aid of cultivation —the realization of the so-called 'Himalayan Dream'.

Similar procedure is likely to prove economic in those regions of Africa where a combination of ground-water resources and hydro-power possibilities may on investigation be found to exist.

9. *The need for speed: methods of drilling wells.*—In scarcity areas when the hope of affording early relief by increasing irrigation is held out, speed of construction is of primary importance. Brief reference must therefore be made to the mechanical method of drilling, as recently advocated for adoption by the Government of India, Agricultural Dept. In the United Provinces tube-wells had been installed, complete for irrigation, at the rate of roughly 500 a year for three years (1934–7), including electrification. These wells were drilled mainly by local contractors operating with small indigenous plants.[1] The strata were usually 'easy', the layout and rudimentary equipment required were cheap, whilst the bonus system of rates offered were attractive to the drilling contractors; moreover, the borings, which were themselves small (mostly 8- or 10-in. holes), were sunk with ordinary casing-pipes to take the permanent tubes and 'strainers'. The drilling rate attained under these conditions averaged roughly 5 ft. per well-day. Such methods are even now, in days of much higher prices, feasible in favourable geological terrains. When, however, during the Bengal famine, the Governments of other provinces decided to adopt tube-wells for irrigation, it proved impossible, owing to the more difficult geological conditions prevailing in the eastern areas, to attain the necessary drilling speed by manual means. When, therefore, proposals were advanced in 1945 for an all-north-India expansion of tube-wells to irrigate an additional 3 or 4 million acres of food crops, a careful study was made of mechanical well-construction in the U.S.A.—notably California—and U.K. Mr. Roscoe Moss, the eminent Californian engineer, in his 1946 report, confirmed the writer's opinion that, if mechanical drilling were adopted, not only could the average drilling speed be increased to 30–40 ft. per day over most of the area, but an improved type of well could be installed, thereby increasing the yield of water for a given expenditure of pumping power. The Government of India accordingly sanctioned in 1946 the 'Central Ground-Water Organization' comprising (i) additional expert staff, both drilling and geological, (ii) mobile mechanical drills of the percussion and rotary types, and (iii) the ancillary equipment necessary for modern wells and power units. The objects were threefold:—(*a*) to explore fresh areas selected for irrigation development, (*b*) to demonstrate the efficiency of mechanical methods, and (*c*) to undertake the construction of a number of irrigation wells (by arrangement with

[1] Comprising a wooden tripod, a pulley, rope, and 'sludger', with a gang of 20 or so ill-paid men.

the Provinces and States concerned) as an integral part of the Grow More Food campaign. As a result, a large number of drilling plants are now being obtained together with the ancillary equipment—and staff—necessary to achieve the targets in the time available. Further details of the organization being adopted can, if required, be obtained from the writer's report of June 1946 to the Government of India. It is recommended that, should an Empire expansion of well-drilling be adopted, similar steps be taken.

10. *Multi-purpose schemes.*—Apart from their use for *local* irrigation (especially in undulating land where a gravity canal would necessarily have to pass through patches of high ground thus left uncommanded), tube-wells can afford other advantages:

(*a*) *Treatment of waterlogged areas.* In the Punjab, where a steadily rising water-table (the result of intensive river-fed irrigation under certain subsoil conditions) is threatening the productivity of immense[1] areas, tube-wells are being installed along (and between) some of the main canal-systems to check the rising ground-water and, incidentally, supplement the canal supplies, thus permitting expansion of irrigation in the desert areas to the south. Similar treatment on a smaller scale has been successfully adopted in the western States of the U.S.A., notably in California and Arizona (the Salt River).

(*b*) *Canal feeder wells.* In localities where river-fed canals pass through tracts having a copious supply of ground-water, large tube-wells, known as 'feeder wells', have been successfully installed in the United Provinces to supplement the canal supplies. Certain minor channels, too, have been supplied from the local ground-water, and cut off from the parent canal, the river-water thus conserved being passed on to dry areas farther south where, for geological reasons, the construction of tube-wells was not found feasible.

(*c*) *Drainage of flooded areas.* Apart from the lifting of low-flowing rivers by pumping on to high lands for 'flow' irrigation, schemes are being evolved for lowering the flood-levels in low areas by means of drainage-pumping.

(*d*) *Drinking-water, &c.* The hygienic value of power tube-wells drawing their supply from sources free from surface contamination, both for drinking-water and bathing, has already been referred to.

(*e*) The introduction of widespread electricity into rural areas, with pumping as a base load to justify the initial outlay, as mentioned above, is an important feature especially in countries where, as in India, the standard of living is often deplorably low.

11. *Personnel.*—If the immediate development of ground-water irrigation in the Empire is to be explored, the question of obtaining experienced staff must be considered. Whereas the supply of engineers with experience of flow-irrigation is fairly good, supplemented as it now is by releases from India, the number of experienced ground-water experts available for the early reconnaissance of vast new areas is very

[1] The water-table is rising at the average rate of 1–2 ft. yearly; moreover, in still larger areas of the Punjab the crop yield is decreasing yearly due to contamination of the soil by alkalinity.

limited. The U.P. scheme was initially carried out by a small band of British and Indian engineers who thereby gained invaluable experience. The cadre has recently been considerably increased but the number of trained British personnel is small and efforts should, in the writer's opinion, be made to establish early touch with retiring engineers. It is further recommended that staff selected for Empire reconnaissance work should be deputed first to visit America to study the latest technique.

12. *Summary of recommendations.*—(*a*) In view of the world scarcity of food grains and the early increase in crop yield that irrigation can secure, it is suggested that an early reconnaissance be conducted in the light of recent Indian and U.S.A. experience into the potentialities of the riverain plains of Africa, and parts of Syria, Arabia, and Iraq (paras. 1–3).

(*b*) In this connexion a close study might well be made of the recent proposals for widespread (3–4 million acres) expansion of tube-well irrigation in alluvial India; also of the organization set forth in the C.G.W.O. report of 1946, based on Mr. Roscoe Moss's review on his air-tour of Jan.–March 1946 (paras. 5 and 9).

(*c*) Mechanical methods of drilling (and the construction of gravel-packed screen wells of the Californian type) should in general be employed; with 'cavity' type wells in suitable formations (para. 9).

(*d*) The possibility of combining irrigation requirements and water-supply for domestic purposes should be carefully studied. The writer's experience in India indicates that sufficient advantage has in general not been taken of this possibility (paras. 5 and 10).

(*e*) The utilization of tube-wells for controlling the ground-water table in saturated areas should be studied in the light of experience gained in Arizona and the Punjab (para. 10 (*a*)).

(*f*) The possibility of supplementing existing (or projected) river-fed canals from the ground-water should be studied. Also of draining flood areas by surface-pumping (para. 10 (*a*) and (*c*)).

(*g*) An investigation into the availability of experienced personnel (especially engineers under release from India) should be made with a view to obtaining skilled staff for reconnaissance duties (para. 11).

REFERENCES

Relevant memoranda on Indian ground-water conditions are contained in the following publications:

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PLANT PROTECTION AND THE FOOD CROPS OF INDIA

PART I. PLANT PESTS AND DISEASES OF RICE, WHEAT, SORGHUM, AND GRAM

G. WATTS PADWICK[1]

VARIOUS estimates have been made of the deficit in supplies of grain and other foodstuffs in India, and of prospective deficits from 5 to 30 years from now. For overall statements of the position reference may be made to *Food and Irrigation Problems affecting India in general and Bombay in particular*, by N. S. Joshi [1], and *A Food Plan for India*, published anonymously with the support of the Council of Chatham House [2]. The latter expressed the view that by 1953 there would be need for an increase in food grains of 14 million tons, to allow for the increase in population, even to maintain the unsatisfactory standard of nutrition prevailing in 1945. The Government of India has recently calculated that there is now an annual deficit of 4 to 5 million tons of cereals based on the existing level of population and on the basis of rations now in force. Statistics relating to food production in India are to be found in *The Food Statistics of India*, by Rao [3].

It is proposed to discuss the losses caused by some of the major pests and diseases of several of the more important food crops, and to indicate the present state of our knowledge regarding their control, and the further research that is necessary. The means of assuring the adoption of control measures will also be discussed, and finally the mechanical equipment needed will be briefly described. Grain-storage pests are not included as they are dealt with by other workers elsewhere.

It should be understood that the estimates of losses due to pests and diseases are mostly based on the personal opinions of workers, and not on sampling tests or accurate surveys. In some cases they are based on the personal experience of the author, and on the opinion of numerous entomologists, plant pathologists, and agronomists throughout India, whom the author visited during a tour of India in 1947. Where published estimates are quoted the source of the figures is indicated.

Losses due to Plant Pests and Diseases and the Present Status of their Control

Major crops only have been chosen. These are rice, wheat, sorghum, gram, potatoes, and sugar-cane.

Rice (Oryza sativa *L.*).—The stem borer (*Schoenobius bipunctifer* Wlk.) was many years ago estimated by Kasargode and Deshpande [4] to cause an average loss of 10 per cent. of the rice crop in Bombay. Rahman [5] states that it is often responsible for the destruction of 90 per cent. of the plants. Other estimates of percentage damage are Mysore 5,

[1] Imperial Mycologist in India, 1937–44, Assistant Director of Agriculture, Bengal, 1944–6, now of the Central Agricultural Control, Imperial Chemical Industries Ltd.

Madras up to 20 in some years, Ceylon 5, and in Assam important losses occasionally. The overall figure of 10 per cent. is perhaps not an over-estimate of the loss, which would thus amount to 3,200,000 tons a year in India. The methods usually recommended for the control of this pest are the removal of dead-hearts at the time of transplanting, catching the moths with light-traps, and ploughing under the stubble to destroy the larvae and pupae. The possibility of controlling the pest with modern insecticides deserves serious consideration.

The swarming caterpillar, *Spodoptera mauritia* Boisd., occurs sporadically, and is often serious in Madras, Mysore, Assam, and Central Provinces. Trehan and Pingle [6] state that it is a major pest all over the rice-growing tract of Bombay. In Travancore, west of Allepy, 150,000 acres are regularly and often severely affected. There is an average loss of at least 2½ per cent. in south India, or 275,000 tons of rice (though the losses are never evenly distributed). Flooding the seed-beds, where this is possible, gives good control. It is, however, very hard to control in broadcast paddy. There is no information as to the possibility of controlling the pest over extensive areas with insecticides.

Leptispa pygmoea B., the blue rice beetle, which damages the leaves, is a major pest in certain districts of Bombay, and occasionally in Assam and other parts of India. In Mysore it affected an area of 10,000 acres in 1946. A suitable insecticide might control the pest.

According to an anonymous report [7], *Hispa armigera* Ol. (*H. aenescens* Baly) is present throughout the year in Assam and Bengal. In 1946 it took a heavy toll on 20,000 acres of crop in the Central Provinces, causing an average loss of over 20 per cent. in the yield in this area. Trehan and Pingle [6] state that it is a major pest in two districts in Bombay. Hedayetullah [8] states that in the season 1939–40 *Hispa armigera* Ol. was controlled by draining the fields and spraying against the adults with a mixture of kerosene emulsion and pyrethrum extract. Pyrethrum dusts and sprays are also said to be effective in Assam. The possibility of using a cheaper synthetic insecticide requires consideration and research.

Paddy grasshoppers, *Hieroglyphus banian* Fabr. and *H. oryzivorus* Carl., attack paddy every year in Madras and are probably widely distributed in India. Rahman [5] regards them as a serious pest in the Punjab; Trehan and Pingle [6] consider them a minor pest in Bombay. Rao and Cherian [9] mention losses of 65 per cent. and in isolated instances up to 90 per cent. in Ganjam District of Madras. These may be exceptional cases, and there are in fact no overall estimates available. The pests have only one brood in a year, laying eggs in the sides of the bunds in the fields. Rao and Cherian [9] recommend the scraping of these bunds to a depth of 2–3 in. immediately after harvest, thus damaging and exposing the egg masses. Subsequent hand-netting of freshly emerged hoppers the next year is considered sufficient to complete the work. However, as the pest migrates from field to field, they point out that active co-operation between neighbouring cultivators is essential. There is plenty of scope here for using one of the new insecticides which have been found so effective for the control of grasshoppers and locusts, provided

always it is used over a wide enough area, co-operative action being presupposed.

Paddy bugs (*Leptocoryza acuta* Thnb. and *L. varicornis* F.), which damage the ears and grains, are particularly common on *aus* paddy in Assam and Bengal, and occasionally cause considerable damage in the Central Provinces. *L. acuta* causes extensive damage in Ceylon in some seasons, especially where paddy is grown as a number of varieties which mature in succession. The control measure recommended there is catching the bugs on sticky cloths. In Madras the official recommendation is hand-picking. Such methods of control are difficult to practise. A chemical method should be simpler.

There are, in addition, minor pests of paddy which generally would not justify the application of special control measures, but which might nevertheless respond incidentally to chemical controls applied to the more important pests. For instance, the paddy gall-fly, *Pachydiplosis oryzae* Wood-Mason, causes considerable losses in certain parts of Madras and Bombay. It has been known to cause severe damage in the Central Provinces, where, according to an anonymous report [7], an outbreak was controlled in 1938–9 by the use of light-traps. The army worm, *Cirphis albistigma* M., can be serious in Bombay. Roonwal [10], referring to the work of Faure in Africa on the South African army worm-moth, *Laphygma exempta* Walker, points to the possibility that the paddy army worm in India may likewise exhibit swarming and solitary phases, which would necessitate the discovery of the permanent homes of the *solitarias* if satisfactory control is to be accomplished. The paddy mealy bug, *Ripersia oryzae* Gr., is a minor pest. Cherian [11] mentions that there are four jassids affecting paddy in Madras, namely, the green spotted jassid, *Nephotettix bipunctatus* F., the white jassid, *Tettigoniella spectra* D., *Erythroneura rubrufa* M., and *Deltocephalus dorsalis* M. Of these, the first two are widespread in Madras, but do not normally do much harm.

The *Helminthosporium* leaf spot [*Cochliobolus miyabeanus* (Ito and Kuribayashi) Dreschler] and similar diseases caused by other fungi, including *Curvularia lunata* (Wakker) Boedijn and *Cercospora oryzae* Miyaki, regularly take a toll of the crop, and in some years the losses may be enormous, as, for example, in Bengal in 1942–3. Of the outbreak that occurred in that year, the Famine Enquiry Commission [12] reported: 'The fungus disease (*Helminthosporium*) was one of the major causes of the serious shortages of the *aman* crop of 1942–3, which was one of the principal causes of the famine.' Unfortunately, there are at present no ready control measures for these diseases; Thomas [13] obtained partial control of *Helminthosporium* leaf spot by immersing the seed for 10 minutes in water at 55° C., but this treatment has not always proved effective and is rather cumbersome. There is no doubt that the control of these diseases would increase the average yield of paddy considerably, and, what is even more important, remove a major cause of seasonal failure. It is desirable that research should proceed in two directions: (*a*) a full study of the biology of the fungi and the epidemiology of the diseases, in order to discover the origin of the epiphytotics;

(*b*) the selecting and breeding of varieties resistant to the diseases, as is being done in the U.S.A. against *Cercospora* leaf spot.

Blast (*Piricularia oryzae* Cav.) is of great importance. It is estimated that 15–20 per cent. of the area under paddy in Mysore suffers an average loss in yield of 25 per cent.; blast is considered the worst paddy disease in Madras. There are considered to be 1,700,000 acres in the worst affected area, approximately half the nurseries of this area being affected each year. The disease is of little importance in the plains of Ceylon, but can cause severe damage in the hills. Even a 10 per cent. loss in the Madras area alone represents a reduction in yield of about 75,000 tons; over the whole of India it must be many times as much. An anonymous note [14] states that the Mycologist and the Paddy Specialist to the Government of Madras have found amongst 1,000-odd varieties of rice some which are highly resistant to blast. The Paddy Specialist has combined resistance with some of the desirable grain- and yield-characters of a susceptible parent. The resistant parent was G.E.B. 24 and the susceptible parent Adt. 10, and strains 10998, 11340, 11348, and 5170 were stated to be becoming popular. However, Thomas [13] reported an almost complete breakdown of the resistance of 10998 and 11348.

Foot-rot or Bakanae-disease [*Gibberella fujikuroi* (Saw.) Woll.] causes damage in a small area, perhaps not more than 20,000 acres, in Madras, and is believed to be the cause of severe injury in some parts of eastern and central United Provinces. It is an interesting disease because, though not one of the most important, it is one which can be very satisfactorily controlled. Sundararaman [15] showed that the disease could be moderately well controlled by immersion of the seed in 1 per cent. copper sulphate solution or by dusting with a proprietary seed-dressing, and Thomas [16] stated two years later that the use of such a mercurial seed-dressing was becoming popular.

Wheat (Triticum vulgare *Vill.*).—Wheat is the second crop in importance as a staple foodstuff in India, though not occupying the second largest area.

Pests cause comparatively little damage to wheat. One of the more serious problems is the damage caused to seedlings by termites. It is estimated that one quarter of the wheat acreage of the Punjab suffers 5 per cent. loss in yield; the Central India States also suffer considerable losses, and the damage extends into the United Provinces. The loss due to this pest is estimated at 300,000 tons. There is at present no solution to the problem, but entomologists are beginning to think in terms of insecticides.

Cutworms cause an average loss of some 3,500 tons of wheat in the districts of Sabour and Mokamah in Bihar. Research on control by baiting with modern insecticides is desirable.

Stem borers (*Sesamia inferens* Wlk. and *Cirphis unipuncta* Haw.) occasionally damage wheat. They were, for instance, noticed causing severe injury in Central India in 1946–7. Whether they will respond to dusting with insecticides as in the case of sugar-cane borers, and whether it will be economical to use them, remains to be proved by experiment.

The rusts, *Puccinia graminis* Pers., *P. triticina* Erikss., and *P. glumarum* (Schm.) Erikss. and Henn., cause heavy losses. During the wheat season 1946–7 the damage caused by rust of wheat in central India (Central Provinces, Berar, and the Central India states) reduced the normal yield of over 800,000 tons to approximately half that figure, whilst the yield was also substantially reduced in parts of Bombay, United Provinces, Punjab, and Bihar. The loss of wheat in India this year due to rust has been estimated in some quarters at 2 million tons. This is an unusually heavy loss, but an average loss of 2½ per cent. or 250,000 tons is certainly not an over-estimate. Mehta [17] estimated the average loss of wheat and barley due to all three rusts in India to be worth nearly Rs. 60,000,000, which at the prices then prevailing would indicate a loss of 444,000 tons, of which perhaps 360,000 tons would be wheat.

Mehta [18] reviewed the knowledge regarding wheat-rust epidemics—knowledge accumulated largely through the extensive research by himself and his colleagues. The most susceptible alternate hosts of black and brown rusts, *Berberis vulgaris* L. and *Thalictrum flavum* L. respectively, do not occur in India. The species of Berberis and Thalictrum found in India are only moderately susceptible. These occur in the hills. Yet the rusts, which cannot survive during the hot summer weather on the Indian plains, break out, year after year, at several places on the plains, in December–January, which is 3 to 4 months prior to the period of the earliest possible infection of their alternate hosts in the hills. The rusts are found to over-summer on self-sown plants and adventitious tillers of wheat and barley in the hills. Wheat sown out of season in the hills becomes infected as early as September–October. It is considered that stray plants and tillers in the hills provide the means of survival of the rusts, which later are carried by wind as uredospores to the plains well in advance of the first appearance of the disease. The number of physiologic races of each rust in India is small. It should suffice, according to Mehta, to breed varieties resistant to rust for growing only in the hills. In the meanwhile, he also advocated 'the rigorous destruction of "out of season" wheat and barley (self-sown plants, tillers and stubble), which carry over the rusts, 1–2 months before sowing in all the hills and hilly tracts'. For the further protection of the crop in peninsular India he recommended the suspension of the first crop of wheat and barley, sown during April to June, in the Nilgiris and Palni hills, and to protect the crop in the Indo-Gangetic plains he suggested the postponement of sowings in central Nepal till October, instead of sowing in April–June.

According to a report of the Department of Agriculture, Bombay [19], a Kenya wheat, E. 144, reported to be resistant at the seedling stage to rust races 15 and 40, proved highly susceptible to all races of black rust, except race 75, when the tests were carried out during April and May under favourable conditions of light and temperature. However, another variety, Holfed 1 from New South Wales, proved resistant to all these races.

Considerable work is now going on in breeding varieties resistant to all three rusts, and intended to be grown in the hills. However, the

success of the project depends upon the reliability of the assumption that it is possible to replace all wheat throughout the areas where the rusts can survive by the resistant varieties and of the conclusion that alternate hosts and grasses are of no significance as regards the wheat and barley crops on the plains. Although the biological conclusions may be correct, the problem of replacing all the susceptible wheats and barleys in the hills by resistant ones may prove to be too difficult an administrative matter to solve. There is much to be said for the breeding also of resistant varieties suitable for the plains, and since, in other countries, it has proved practical to combine rust resistance with high quality and good yields, it should certainly not prove impossible in India, where it has been demonstrated that the number of physiologic races of the rusts is small. In any case, there is full justification for intensifying the efforts to breed resistant varieties, for there is no other economical method of controlling these diseases.

Loose smut [*Ustilago tritici* (Pers.) Rostrup] causes considerable and steady losses all over India. Occasionally infection is severe. Luthra and Sattar [20] recorded 30 per cent. infection in the Upper and Lower Jhelum canal colonies in the Punjab in 1923. Attacks up to 10 per cent. were common, and the annual loss in the Punjab at the low prices then prevailing was estimated at £400,000. Even at 1 per cent. the loss in yield over all India is 100,000 tons. Luthra and Sattar [20] modified the Jensen hot-water treatment. They established that the disease could be controlled by immersing the seed in a blackened iron vessel of water and then standing it in the sun for 4 hours, and afterwards drying the seed, or by soaking the seed in water from 8 a.m. till 12 noon and then removing it and exposing it to the hot sun from 12 noon till 4 p.m. Luthra [21] stated that the method is largely in use among cultivators. Mundkur and Pal [22] tested the reaction of over 100 varieties of wheat (mostly from northern India) and certain hybrids, and found a large number, including I.P. 114, I.P. 120, and I.P. 165, either immune or highly resistant. Only one physiologic race was used. Later, Pal and Mundkur [23] continued this work using two races of the fungus, and found a large number resistant or nearly immune, including some of the stem-rust-resistant Kenya Wheats.

Flag smut (*Urocystis tritici* Koern.) severely damages wheat in the submontane areas of the Punjab, causing an average loss estimated at 5 per cent. in yield, or 15,000 tons for the whole area. Pal and Mundkur [24] found 20 varieties of the 97 tested to be highly or completely resistant to flag smut. They included the important varieties I.P. 4 and I.P. 111, but the varieties I.P. 120 and I.P. 165, which were highly resistant to loose smut, proved to be susceptible to flag smut. There would appear to be need for further work, in an attempt to combine resistance to loose and flag smut, at least for the submontane tracts.

Bunt [*Tilletia caries* (DC.) Tul. and *T. foetens* (Berk. and Curt.) Trel.] does not attack wheat on the plains, but occurs in the hills in most severe form, causing a loss of from 5 to 20 per cent. in Baluchistan, whilst as much as 40 per cent. infection is not uncommon in Kashmir. However, the area of wheat grown in the hills is small. Above 5,000 ft.

altitude the loss might be 10 per cent. All wheat grown above this altitude should be treated before sowing with a suitable seed-dressing.

Karnal bunt [*Neovossia indica* (Mitra) Mundkur] causes only low infection over a large area of the plains, except for a severe attack in 1940–1. The loss in yield is small, as only individual grains are attacked. Seed-dressings are not likely to be effective against this disease which, apparently, is not seed-borne.

Foot-rot, due to *Helminthosporium* spp., causes a decrease in yield of about 5 per cent. in late-sown crops in the Central Provinces and adjoining areas, or say an average loss of 3 per cent., which means about 30,000 tons. It is also believed to be important in the Punjab, particularly in the rain-fed areas of the submontane parts of the plains adjacent to the Himalayas. Dastur [25] observed that the disease is very much worse when the crop is sown early after a deficient monsoon, as in the early sowings the temperature is high and favours the development of the disease. It is believed that the losses could be substantially reduced by seed-dressings.

Sorghum (Sorghum vulgare *Pers.*).—Deccan wingless grasshoppers (*Colemania sphenarioides* Bol.) cause severe damage in south India. The estimated loss in yield in Mysore is 20 per cent. over 355,000 acres, or at least 10,000 tons. Over the whole of the Deccan the loss may perhaps be estimated at 180,000 tons. Subrahmanyan [26] states that outbreaks occur in cycles of 10 to 15 years, taking 3 or 4 years to reach their peak, appearing in the same scattered areas each year. Recommended control measures are catching in a bag dragged rapidly over the crop by hand or by bullocks, and dusting the grass strips with calcium arsenate or Paris green. Seshagi Rao [27] states that alternating sorghum with cotton and groundnuts, which are not much damaged by grasshoppers, and sowing sorghum more thinly, reduces the attack. A 1:3 dust of sodium fluosilicate in rice-bran applied to grass strips gave 70 to 80 per cent. reduction in the hopper population after 48–72 hours, not apparently by killing, but by causing mass migration from the areas. A bait of fluosilicate 1:9 or 1:5 with salt and water reduced the hoppers but slightly scorched the plants. The use of more effective grasshopper insecticides is now being tried in Bombay.

The most destructive pest of sorghum in India, according to Rahman [28], is the borer, *Chilo zonellus* Swinh. *Sesamia inferens* Wlk., another borer, is also a major pest in Bombay, according to Trehan and Pingle [6]. *Chilo zonellus* is estimated to cause 10 per cent. loss in yield in the Central Provinces, and may be typical of the whole of India. If so, it is a pest of outstanding importance, being responsible for a loss of 745,000 tons of valuable food grain. Rahman [28], working with maize, found that delay in sowing until on or after August 7, instead of sowing in mid-July, resulted in a reduced incidence of the pest. Before this method could be adopted with sorghum, it would be necessary to carry out yield trials, and the advantage of controlling the pest might be countered by loss in yield from sowing out of season. The use of insecticidal dusts, as with sugar-cane borers, requires to be tested.

The red hairy caterpillar, *Amsacta moorei* Butler, is a major pest in

north Gujerat, Bombay, where in some years it strips all the plants of their leaves. Pruthi and Bebraw [29] find that an effective catch of the moths can be obtained by using a 200-candle-power petromax lamp for every 15 acres. This lamp is placed above a dish of water with a thin layer of oil floating on top, and has to be set up on the night immediately following the first heavy monsoon shower, and continued during the period of emergence of the moths, which lasts for about a month with each of the three broods. In 1939 the cost worked out at Rs. 1/2/- per acre. The method was supplemented by hand-picking the caterpillars and by isolating infested fields by digging trenches 8 in. deep and 10 in. wide around them. The use of an insecticide might also be considered here.

The mite, *Paratetranychus indicus* H., which sucks and dries the leaves, is a major pest in Bombay and is also important in Mysore. There is no satisfactory control measure, and a good acaricide is awaited.

Cherian, Kylasam, and Krishnamurthi [30] state that the ear-head bug, *Calocoris angustatus* Leth., causes damage to sorghum in Madras and Mysore. A proprietary sulphur dust applied immediately after emergence of the ears or 4–8 days later, and again after an interval of 6 days, failed to give significant control. The testing of other insecticides seems desirable.

Grain smut [*Sphacelotheca sorghi* (Link) Clinton], which occurs throughout the area where sorghum is grown, is considered to cause an annual loss in yield of 5 per cent., though there are large tracts in which it may be higher. At this figure, the annual loss is 325,000 tons. Good control can be had very cheaply by dusting the seed with sulphur. Kulkarni [31] and Padwick and Mundkur [32] found that quite crude sulphur from Baluchistan, containing as little as 56–75 per cent. sulphur, gave excellent control of smut, indicating that the high degree of fineness and purity usually considered important is not essential for controlling the disease in India. However, one aspect of the problem that has been overlooked is the significance of leaf-diseases. The fungi concerned include *Titaeospora andropogonis* (Miura) Tai, *Colletotrichum graminicolum* (Ces.) Wilson, *Helminthosporium turcicum* Pass., and *Curvularia lunata* (Wakker) Boedijn. The effects on yield are not known, but judging by the extensive spotting of the leaves, must be considerable. It has not been shown that these diseases, which are partly seed-borne, part air-borne, and part soil-borne, are controllable by sulphur. Extensive trials are necessary with sulphur, mercurials and copper compounds, and organic seed-disinfectants, to determine whether in India, as in the U.S.A., some of these prove to be better than sulphur.

Parasitic flowering plants (*Striga* spp.) are well established on sorghum in Bombay, Central Provinces, and Hyderabad. The loss in yield in these areas in an attacked crop is always high, and may be up to 50 per cent., though the pest is not universally distributed. The Department of Agriculture, Bombay [19], records that five varieties are highly resistant to *S. lutea* Lour. and that one of these is also definitely resistant to *S. densiflora* Benth. The tackling of the problem by dusting or spraying with one of the selective weed-killers of the plant-hormone type deserves consideration.

Gram (Cicer arietinum *L.*).—Gram caterpillar, *Heliothis obsoleta* F., commonly causes severe damage in the Punjab, the Central Provinces, Central Indian states, and Bombay, both destroying the young seedlings and damaging the pods. There is at present no satisfactory method of controlling the pest, and research on insecticides seems desirable.

Gram cutworm, *Agrotis flammatra* Schiff., is sporadic and is sometimes a serious pest, especially in south-eastern Punjab, where Rahman [5] states that sometimes 50 per cent. of the crop is destroyed. It can be controlled fairly well by using Paris green baited with bran and 'gur' (unrefined sugar), but this method is not yet widely adopted. Another cutworm, *Agrotis ypsilon* Rott., is considered a major pest in Bombay.

The worst disease of gram is, undoubtedly, wilt. The extent of the losses has never been determined with any degree of accuracy. The disease appears to be a complex of several root-diseases, Prasad and Padwick [33] having shown that it can be caused by a species of Fusarium, whilst Kheswalla [34] demonstrated that it can be caused by a pycnidial fungus, *Operculella padwickii*. On the other hand, Dastur [35] considered it to be partly due to *Macrophomina phaseoli* (Maubl.) Ashby and partly of non-parasitic origin. The death of plants due to wilt sometimes takes on alarming proportions over large areas, particularly in the drier portions, of the 16,000,000 acres devoted to the crop. Padwick [36] showed that wilt caused by *Fusarium orthoceras* var. *ciceri* Padwick develops most readily at comparatively high temperatures. The only hope of control at present seems to lie in the fact, demonstrated by Padwick and Bhagwagar [37], that delaying the date of sowing until the middle of October substantially reduces the losses. Luthra, Sattar, and Bedi [38] confirmed the advantage of delay in sowing. Delay beyond the middle of October, although resulting in still further decrease in infection, causes a poor and late development of the plants.

Gram blight (*Mycosphaerella rabei* Kov.) is a disease of comparatively limited geographical distribution but great severity. It occurs mainly in the district of Attock in the Punjab, according to Luthra and Bedi [39], and Luthra, Sattar, and Bedi [40] state that this district, which grows 100,000 acres of gram, lost half its crop annually from 1920 to 1930. Luthra and Sattar [41] estimated the loss at 30–40 million rupees a year. Luthra, Sattar, and Bedi [40] found that gram blight could be controlled by the use of disease-free seed, the elimination of diseased plant debris, and by mixed cropping of gram with wheat, barley, and mustard. Luthra, Sattar, and Bedi [42] tested the resistance of 187 varieties of gram from India, America, and Europe, and found four resistant types from America, which had originated in France. One type, bearing the accession number F 8, was widely distributed, Luthra and Sattar stating that 22,000 maunds of seed were produced in 1941. Unfortunately, this variety was found to be highly susceptible to wilt. However, two progenies of a cross between F 8 and a local type (Pb. 7), known as C. 62–18 and C. 12–34, have been found satisfactory in yield and quality, resistant to blight, and not especially susceptible to wilt, according to Luthra, Sattar, and Bedi [38]. Blight is therefore no longer the serious problem it once was.

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PLANT PROTECTION AND THE FOOD CROPS OF INDIA

PART II. PLANT PESTS AND DISEASES OF POTATOES AND SUGAR-CANE; ORGANIZATION, MACHINERY, AND EQUIPMENT FOR PLANT PROTECTION

G. WATTS PADWICK

Potatoes (*Solanum tuberosum* L.).—The inclusion of potatoes in this survey would not be justified on the grounds of acreage, which before 1939 was only about 400,000 acres. They are included because they are becoming more and more widely consumed in India; the acreage is consequently growing, and the crop may serve in future as a valuable dietary supplement to wheat and rice.

According to an anonymous [43] publication, a cutworm of the genus Spodoptera damages potatoes in the Kumaon Hills of the United Provinces. *Agrotis ypsilon* Rott. is considered to be a major pest in Bombay and Central Provinces. Cutworms also attack the crop in the Punjab and the Central Provinces. In the United Provinces the hill areas suffer particularly. In Punjab and the United Provinces *Agrotis flammatra* is responsible, probably also other species. It would perhaps be conservative to estimate that one-tenth of the area under potatoes in India, i.e. 40,000 acres, is more or less affected by cutworms, causing a total loss in yield of perhaps 400,000 maunds or 16,000 tons. The method of control recommended in the United Provinces is poisoning with white arsenic or Paris green baited with bran, molasses, and orange or lemon juice, pulp, and peel.

Epilachna dodecastigma Muls. and *E. vigintioctopunctata* F. cause damage to potatoes both in the hills and on the plains of India [43]. Lime-sulphur was the only insecticide found to give any control of these leaf-eating beetles; it required two applications. Avoiding the growing of cucurbits and solanaceous plants was recommended as the best method of control. The use of other insecticides deserves trial.

Probably the most serious pest of potatoes is the tuber moth, *Gnorimoschema operculella* Zell. (*Phthorimoea operculella* Zell.). This pest does its greatest damage to the tubers in storage, but can also attack the foliage in the field and is liable to be brought into the stores along with infested haulms or tubers. The caterpillars are one of the most important causes of the enormous losses of tubers during the long period of storage. The pest causes heavy damage in Madras, Central Provinces, Assam, Bombay, and Bengal. In Bengal it is thought to cause often the destruction of as much as 50 per cent. of the tubers. Though the actual amount may be greater, we may certainly estimate the losses all over India at 10 per cent. of all tubers stored for more than 3 months, which must be at least 400,000 tons, giving a loss of 40,000 tons, much of which is valuable seed-material.

We may first consider the possibility of controlling the pest in the field by spraying and dusting, with a view to preventing any appreciable

number of the insects being brought into the stores. We can only depend for guidance on work done outside India. Lloyd [44] carried out extensive experiments on the control of potato moth by spraying and dusting in the field and by treatment of tubers with insecticides. Foliage sprays and dusts included lead arsenate, basic copper arsenate, calcium arsenate, Bordeaux mixture, nicotine sulphate, derris, and colloidal copper sprays; and lead arsenate, calcium arsenate, and derris root as dusts on kaolin base. Derris dusts and sprays gave the best control in the field, the former being a derris 1:4 (kaolin) dust containing 0·94 per cent. rotenone and the latter a spray of 3 lb. derris in 100 gals. of water. Helson and Greaves [45] have shown that good control of the pest on the foliage can be had by the use of a 0·1 per cent. D.D.T. solvent naphtha emulsion, at the rate of 110–20 gals. per acre, or 2 per cent. D.D.T. dust, at the rate of 30–40 lb. per acre. However, Lloyd [44] in his experiments, where small plots were treated, found that the control of the pest on the foliage did not reduce tuber infestation, probably due to invasions from outside areas. Of the various dusts tested on stored tubers, derris and kaolin (1:4) proved best in preventing spread of infestation. Products which other workers have found effective or promising are magnesite, pyridine, kieselguhr and kaolin, methyl bromide, carbon bisulphide, paradichlorbenzene, acetylene, and petrol.

In India most of the research on the control of the tuber moth has been related to the various methods of storing the tubers. Rahman [46] produced evidence that loss of tubers due to moths was less when they were stored on racks than when stored on the floor, and that covering with a 1-in. layer of dry chopped *Lantana*, sawdust, grass, or *bhusa* (chaff or short straw) very greatly reduced the tuber-moth damage. Lal [47] disputed Rahman's conclusion that storage on racks is preferable to storage on the floor, as the results were too erratic. He was unable to confirm the results of using sawdust, *bhusa*, and *Lantana* leaves, though he found sand, ash, and ash mixed with lime to be very effective, thus confirming the old findings of Lefroy and Evans [48]. The findings of Rahman are also disputed by Bhatia [49] on the grounds that artificial infestation of the storehouses was not representative of natural conditions. Trehan and Bagal [50] found that naphthalene balls placed amongst small lots of potatoes reduced oviposition, and prevented the hatching of eggs that were laid. It is not mentioned whether the flavour of the tubers was affected. There can be little doubt that tuber-treatment is much the more practical method of controlling the tuber moth. The search for an insecticide which is cheaper and easier to apply than the fumigants at present used will doubtless lead to a very substantial improvement in potato storage in India.

Of the diseases of potatoes, late blight (*Phytophthora infestans* de By.), which is so important in many countries, attacks the crop in India only in the hills. It causes heavy losses in Assam and Bengal, and somewhat smaller losses in the United Provinces and Punjab. The actual loss in crop, say 10 per cent. of all the potatoes grown in the hills, is small, but much of this is grown for seed to supply to the plains. The disease is later responsible for further loss in storage. Mundkur, Pal, and Nath

[51] found the majority of varieties cultivated in India highly susceptible, and only a small number showed any degree of resistance. Ultimately, perhaps, control will lie in breeding resistant varieties. Spraying to control the disease is rarely practised.

Early blight [*Alternaria solani* (Ell. and Mart.)] affects the crop in both hills and plains. There is no estimate available of the damage caused. The possibility of control by the use of copper sprays is under consideration, but the method is not likely to be adopted unless it proves economical, and it is doubtful if the disease does sufficient damage in most places to make it so.

Virus diseases are probably the greatest single cause of poor yields of potatoes in India. Pal [52] recorded the presence of potato virus Y in very high percentages of potato plants of the important commercial variety known as *Phulwa* or *Patna White*. He also records the occurrence of leaf-roll in India. Vasudeva and Lal [53] isolated a virulent strain of potato virus X from Majestic potatoes from Bhowali, a foot-hill region of the Himalayas of the United Provinces. The same authors [54] also isolated both potato virus X and potato virus Y from the varieties Gola, Majestic, President, Windsor Castle, Up-to-Date, and *Phulwa*. On the plains at least, infection with these two viruses is widespread, and it is difficult to obtain disease-free stocks. The crops in the hills tend to be somewhat healthier. Attempts are being made to secure and multiply disease-free 'seed', with a view to establishing stocks for starting a seed-potato certification scheme. Breeding for virus resistance is also to be undertaken.

Sugar-cane (*Saccharum officinarum* L.).—The area under sugar-cane in India is about 4 million acres. It is an especially interesting crop because the manufacture of sugar is a major industry, a fact which has been reflected in the improvement of cane cultivation.

Leaf-hopper (*Pyrilla perpusilla* Wlk. and *P. pusana* Dist.) are widespread pests. During the 1930's there were three epidemics in the United Provinces, i.e. during 1930–1, 1934–5, and 1937–8. The recovery of sucrose in nine districts of the United Provinces during the Pyrilla year 1934–5 was reduced by one-third to 6·4 per cent. Mathur and Gupta [55] considered Pyrilla attack to be the chief cause of deterioration of the sugar-cane crop of Meerut and Muzaffarnagar districts in 1937–8. In 1947 there was another severe outbreak affecting 80,000 acres in western United Provinces. A loss of 10 per cent. of the sugar in Punjab, the United Provinces, and Bihar, which is perhaps a fair estimate, means 280,000 tons of sugar. Sadik and Singh [56] claim successful results in controlling leaf-hoppers of sugar-cane over an area of 186 acres by catching the hoppers in nets between the hours of 8.30 and 11 a.m. and again from 4 to 7 p.m. During these hours the hoppers are somewhat sluggish. The method was supplemented by crushing the egg-masses. Though this and similar methods are fairly effective, and are actually used to some extent by cultivators, they are tedious, and if a less laborious control measure can be found it may be taken up readily by growers.

There are a number of cane-borers occurring in India. The top-borer

(*Scirpophaga nivella* Fabr.) is a widespread pest, causing an estimated loss of 5 per cent. over one-tenth of the cane area of India, or 20,000 tons of sugar. Top-borers often kill up to 80 per cent. of the shoots in the early attacks; regrowth takes place, but there is a loss in yield. The two stem-borers *Argyria sticticraspis* Hmps. (*Proceras sticticraspis* Hmps.) and *Diatraea venosatus* Wlk. (*Proceras venosatus* Wlk.) also cause considerable damage. Twenty per cent. killing of the young shoots is common with reduction of 0·5 per cent. of sucrose. Other borers also causing damage are *Sesamia inferens* W. and *Chilo trypetes* Bisset.; the root-borer *Emmalocera depressela* Swin. kills the young plants occasionally. The Department of Agriculture, Bihar [57], recorded the loss in cane tonnage due to all borers as 5·7 per cent., and the decrease in sugar recovery as 0·43 per cent., in 1939–40.

Control of the sugar-cane top-borer has mostly been based on manual methods. Sadik and Singh [56], for instance, report considerable success in a campaign against top-borers in a rather small area in the Punjab, by hand-picking the moths and crushing the egg-masses. This work is laborious, and it would be difficult to get it regularly carried out over a sufficiently wide area. The use of chemicals to control the pest might prove to be economical in those areas where it is really serious.

Hitherto, attempts to control the stem-borers in India have been along two lines—control by cultural methods, and biological control. Venkatacharya [58] states that the borers *Argyria sticticraspis* and *Diatraea venosatus*, in the Irwin Canal area of Mysore, could be controlled by two light earthings-up of the setts, the first as soon as they begin to shoot, and the second about 3 weeks later. Cutting out the dead hearts and collecting the egg-masses are considered impracticable. Gupta [59] showed that earthing-up of sugar-cane early in the season (starting in May, and again in June and July, as compared with August) substantially reduced the percentage of the canes bored by *Argyria sticticraspis*, but repeated earthings-up were inclined to reduce yield slightly. As a practical measure, control by early earthing-up has not been universally accepted, and much attention has been paid to biological control. A considerable amount of natural biological control takes place. The biology of some of the parasites concerned is described by Rahman [60]. Isaac [61], who experimented in Bihar, showed that mass liberations of *Trichogramma minutum* Riley gave some reduction of attack of canes by stem-borer, *Argyria sticticraspis* (reduced from 29·4 to 10·2 per cent. at Lalseriah and from 14·7 to 12·2 per cent. at Madhopore), and by root-borer, *Emmalocera depressela* (reduced from 43·2 to 21·2 per cent. at Lalseriah and from 31·7 to 9·2 per cent. at Madhopore). These results indicate that control by this parasite is far from complete. Subrahmanyam [62] stated that *Trichogramma minutum* was being reared on an increasing scale in Mysore, and has resulted in up to 90 per cent. parasitization of eggs of *Argyria sticticraspis* and *Diatraea venosatus*, and raised the yield of cane by about 3 tons per acre in 1938. He points out that this method alone will not give complete control, but must be supplemented by other methods. His laboratory could produce enough parasites to control borers on 1,000 acres of cane.

Although work is now in progress in India on the use of chemicals for the control of the sugar-cane borers, no published results are yet available. Some information is available from America, which may hold out promise for India. Dugas and Ingram [63] found that four applications of 5·91 lb. of cryolite dust per acre applied at weekly intervals against first-generation larvae reduced the number of canes bored to less than 10 per cent. of those in the controls. Against the second generation larvae it was less effective. Annand [64] claimed that cryolite dusted four times at weekly intervals during the first and second generations of larvae gives excellent control. However, Dugas [65] points out that to get complete control of borers no single measure will suffice; care in selection of uninfested setts, burning of trash, cutting the cane at or just below the ground level, and removing all cane, whether millable or otherwise, at harvest-time, are all essential.

As a result of damage by termites, it is estimated, 10 per cent. of the acreage of cane in the Punjab suffers an average loss of 800 lb. of setts (cuttings) and over 3,000 lb. in yield of cane per acre, whilst in the United Provinces and Bihar the area affected may be as much as 25 per cent. This represents a loss of 100,000 tons of sugar. Work is now proceeding in testing chemicals for the protection of the setts.

What seems to be most desirable now in the control of sugar-cane pests is an effort to tackle them on the broadest possible footing. Some of the newer insecticides, applied in the form of dusts or sprays, may help to reduce the incidence of not one pest, but several. Yet it seems from the evidence so far accumulated that there is not likely to be a 'cure-all', and that cultural methods will also have to be used. Cognizance will also have to be taken of the danger of reducing the population of parasites which normally help to keep down some of the pests, especially the borers. Restriction of efforts to one single pest leads to the recommendation of methods which have various drawbacks rendering them useless in practice.

Amongst the diseases of sugar-cane, none has caused greater havoc than red rot (*Colletotrichum falcatum* Went.). Chona and Padwick [66] stated that over an extensive area the amount of sugar-cane crushed during 1938–9 was reduced to about one-third of the normal amount, and in 1939–40 to about one-half of the normal. When the outbreak became very severe, drastic steps were taken to end it and to prevent its recurrence. Padwick [67] recommended the setting aside of small plots of well-drained land for growing seed-cane material, with frequent rogueing to ensure disease-free setts being available in sufficient numbers. The ultimate control might lie in disease-resistant varieties, though careful sett selection would always be desirable. Chona and Padwick [66] later found that infection of healthy setts also takes place readily from infested debris and from spores or mycelium in the soil, and that secondary infection is common, which further emphasizes the desirability of producing resistant varieties. Chona [68] listed 23 varieties found by him to be most susceptible over a period of years.

Smut (*Ustilago scitaminea* Syd.) causes much less damage than red rot. However, Chona [69] records a number of cases of heavy infection,

in some instances as much as 50 per cent. Luthra and Sattar [70] summarized results of experiments in the control of sugar-cane smut, and showed that it could be controlled by avoiding the use of 'setts' (cuttings) from smutted canes; immersing the setts in 1 per cent. formalin solution for 5 minutes, then covering for 2 hours with moist gunny sacking; removing all smutted plants as they appeared; and avoiding ratooning of smutty crops. Chona [69] doubted the effectiveness of chemical disinfection of setts from naturally infected material (internal infection). In rogueing, he pointed out, it is essential to remove entire clumps, and not merely smutted canes.

The phanerogamic parasites, *Striga* spp., are taking an ever-increasing toll as they spread to new areas in flood-water and irrigation channels. In the district of Saran in Bihar the area concerned is about 160 sq. miles, one-quarter of which is under cane. The infestation came suddenly, following a severe flood in 1942–3. The cane lost 12 per cent. in juice quality and 18–25 per cent. in yield, representing about 8,000 tons of sugar. It occurs also on cane in the Deccan and United Provinces. An anonymous writer [71] states that Striga in sugar-cane can be controlled satisfactorily by soaking the soil to a depth of 4–6 in. near the base of the cane plants with a 3 per cent. solution of copper sulphate. It is claimed that treatment for two successive years completely controlled the disease in a badly infested field. It is a fairly expensive treatment. Experiments are now in progress in India to determine whether this pest can be controlled by the use of a selective weed-killer of the hormone type.

Organization of Plant Protection

We have seen how, by the application of measures at present known, or which seem nearly developed, for the control of pests and diseases, it is possible to increase by several million tons the food output of India. This gain is to be had as a result of controlling only a small number of pests. Actually, there are good chances of controlling some thirty or more pests and diseases of India's important crops.

The question now to be considered is whether the Indian cultivator can and will adopt the necessary measures for plant protection which would go so far towards solving the immediate food problem. Hitherto, cultivators have adopted very few practices specifically for the control of plant diseases and pests, and it is not to be expected that they will readily take up such measures unless they are thoroughly and convincingly demonstrated. However, the cultivators have taken enthusiastically to the use of inorganic fertilizers, and there is reason to suppose that they would do likewise with pest-control measures when once convinced.

The number of cultivators in India is probably about 60 millions. Of these, only a small proportion, probably less than 20 per cent., can read and write. There is little opportunity, therefore, to approach them through the medium of the printed word. The radio is insufficiently common to be very useful. Propaganda through the cinema, the spoken word, and demonstration farms can likewise reach but a very small proportion of the farming community. The Governments of India, realizing these difficulties, are now favouring the actual carrying out of

plant protection on the farms of the cultivators, through the Government staff.

The Government of India has for some time been attempting to persuade the provincial Governments to adopt plant-protection schemes, and has included an example of such a scheme in *Outline of an Agricultural Plan*, published by the Central Department of Agriculture [72]. Owing to the special technical knowledge required, it is considered the provinces should employ staff trained in plant-protection work as guides and demonstrators to the general extension staff and the cultivators. Under the scheme, the actual control operations would be carried out by the subordinate staff for general extension work. Chemicals and machinery and equipment, as well as technical advice, would be provided by the Government, but the labour would have to be provided by the cultivators. After a year or so the question of charging a part of the cost of insecticides and spraying machines to the owners of the crop, particularly of fruit orchards, would be considered.

The success of a Government campaign for the control of a pest or a disease will depend on the scale and nature of the operations and the ability of the staff to operate over a sufficiently large area. This is especially true when reference is made to attempts to take early measures preventing the spread of pests. Striking examples of this may be seen in the case of the Deccan wingless grasshopper, paddy-bugs, paddy-swarming caterpillars, red hairy caterpillar, and sugar-cane leaf-hopper. Indeed, even in the case of fungus diseases we have the example of gram blight—a disease which certainly could have been controlled by hygienic measures alone had all cultivators co-operated. If the mobile Government staff is doing the work, their attempts will fail unless a sufficiently large area can be covered very rapidly.

Almost all the crop area that really matters consists of quite small fields, whether it be paddy, wheat, jowar, sugar-cane, or any other major crop. The Famine Enquiry Commission in its report [12] pointed out the difficulty of expressing the size of holdings and farms, even where the necessary statistics are available. In Bengal a survey of 19,599 families indicated an average holding of 4·4 acres, with only 8·4 per cent. having holdings above 10 acres. In the United Provinces the average is 6 acres, but the district average varies from 4·8 acres in the fertile division of Gorakhpur to over 12 acres in the unfertile Jhansi division. Madras has an average of 4·5 acres. In Punjab 63·7 per cent. of owners have holdings under 5 acres, yet the average holding is probably around 10 acres. In Bombay the average is 11·7 acres. These acreages represent, it will be noted, the sizes of *holdings*. The fields are much smaller. Generally speaking, there are few large and unbroken blocks of a single crop of wheat, sorghum, gram, sugar-cane, &c., though there may be large areas in which individual fields are separated merely by fallow land. Often, however, fields are widely separated; if not, they belong to a large number of different owners. Rice, it is true, forms a fairly unbroken coverage over many square miles of land in some parts of India, the only break being the occasional clump of trees and villages, with a few other crops on high ground. Even so, there are numerous owners, and each

owner may have several fields located at places some distance from one another and separated by land belonging to another owner ('fragmentation' of holdings).

Control measures against such a pest as sugar-cane leaf-hopper in northern India may involve the dusting or spraying with an insecticide of, say, 100,000 acres. However, that may be in the form of scattered fields covering half a million acres. In paddy, for the control of the swarming caterpillar, there is one area of 150,000 acres of almost unbroken paddy fields in Travancore; but there are scattered areas affected in many parts of south India. It may at times be necessary for the plant-protection staff to travel half a mile or more from one infested field to another, but at other times they may have large and comparatively compact blocks of fields to dust or spray.

The availability of water-supply may be an important factor in deciding the form in which insecticides are to be used. Water is often scarce, and insect pests are often worse under drought conditions. Furthermore, the use of a spray necessitates the hauling of large quantities of water and the use of more complicated machinery than the use of dusts. On the other hand, where a spray can conveniently be used, it may be more economical of the chemical, and the latter may adhere better and have a more persistent effect than the dust. It is probable, therefore, that for protective fungicides sprays will be found more effective than dusts, but with some of the cheaper new forms of insecticides dusting may prove to be more economical.

Machinery and Equipment for Plant Protection

It has been shown that there are many pests and diseases of crops that can be controlled by the use of chemicals. There is, however, one very important limiting factor. It is possible to carry out these control measures only if the dusts or sprays to be used can be applied quickly and effectively, over a very large area. The difficulties inherent in such work in India are the smallness of the holdings, the large number of cultivators, their illiteracy, the small fields surrounded by *bunds* and irrigation channels, and the poor communications. It will at once be obvious to anyone who has experience of the use of large-scale farming equipment in western countries, that this type of equipment cannot be used under the conditions prevailing in India without very much modification. A tractor with a spray boom, for instance, cannot be taken over high bunds and irrigation channels without causing great damage. Nor can it be taken where there are no roads, without damaging the crops. Dusting and spraying from aircraft is sometimes considered, but there are many areas where it is not practical because of the hilly nature of the country, the patchiness of crops, and unsuitable climatic conditions. Yet it seems obvious that, since the work has to be done by specially trained staff, who will naturally be limited in numbers, the use of power-driven machines is very much to be desired, and may even be essential for the success of the schemes. It is also obvious that plant-protection staff will have to be as mobile as possible, so that ideally the equipment should be capable of being readily mountable in small trucks and trans-

ported over distances up to at least 200 miles from headquarters. Put briefly, equipment should have the following characteristics:

1. *Portability*. It must be capable of being carried by hand in the fields, but it would be an advantage if it were also quickly mountable on wheels so as to be transported as a trailer over longer distances. The weight should not exceed 200 lb.
2. *Power*. The use of power-operated machines is justified from the point of view of speed of operation and coverage of large areas. There may, however, often be areas which can most conveniently be dealt with by hand-operated machines.

It is important to remember that the weight of machines is bound up with power, system of cooling, type of chassis, and method of supplying the dust or liquid. For power, weight for any given design of machine is roughly proportional to horse-power. Water-cooling nearly doubles the weight of the engine, and adds, at least for the lower horse-power units, about 75 per cent. to the total weight of engine plus pump. A wheeled chassis is considerably heavier than a hand-carrier chassis. The combination of a tank for fluid along with the pump and engine increases the weight to such an extent that this system is entirely ruled out wherever it is desired to carry the machine by hand.

Having outlined the general principles behind the selection of equipment, we may pause for a moment to consider what type of equipment is already in use in India for the only crops where spraying and dusting are already extensively adopted—the plantation crops, tea, coffee, rubber.

For tea, the machines most commonly used are knapsack sprayers with a hand-operated pump built in. They are mostly of 2-gallon capacity. They are convenient for spraying small numbers of bushes against black rot, &c. Knapsack battery sprayers, which are filled and pumped to pressure at a central point, are used for larger numbers of bushes. Generally speaking, large acreages cannot be covered with such machinery in a short time.

For the control of rust in coffee, double-action suction pumps operated by hand-levers, with working pressures below 100 lb. per sq. in., are popular. They are moderately efficient, easy to repair and maintain, but require considerable labour. Power-operated suction-pump sprayers, with $1\frac{1}{2}$ to 3 h.p. motors, carrying up to 8 lances and 16 nozzles on 300 ft. of hose, with working pressures from 100 to 300 lb. per sq. in., are coming into favour. Similar types of machine are used for spraying rubber, the spray operator having to climb the trees to spray them effectively. With labour conditions as they are at present (1947), power spraying is considerably cheaper than hand-pump spraying. On a 1,200-acre rubber estate in south India, one spraying with Bordeaux mixture (3:3:45) costs Rs. 9/9 per acre for labour, Rs. -/7 for fuel, and Rs. 9 for spray materials, per acre, when a power machine is used; with hand-operated pumps the cost of labour is Rs. 17/4. Even with the power machines, a large amount of labour is still used in carrying water, and a further substantial saving should result from the transport of water

and spray fluid from the water-supply and the mixing points to the fields by power-operated low-pressure pumps.

In Ceylon rubber is dusted with sulphur for the control of powdery mildew (*Oidium heveae* Steinman). For this purpose, power-dusters are used, with motors from 1½ to 3½ h.p. operating a fan creating an air-blast. The whole apparatus can be carried on poles by four coolies.

We have in these two types of power machine, used on Indian plantations, something approaching the requirements of portability and power outlined above for machines to be used in field crops in India. The suction pumps have sufficient power, and the weight of the machines is within the limit of 200 lb. The spray solution is in a separate container, which can be of any convenient size so long as it is frequently replenished. Some machines of this type are already being built on a rubber-tyred chassis from which they can easily be lifted, the necessary carrying-poles being fitted in a matter of minutes. The spraying of coffee has been done with numerous nozzles on a considerable number of lances and hoses. In this way much of the pressure is lost. For field crops the pressure is needed, and the hoses should be reduced in number to maintain it. Fine nozzles are not necessary, it being preferable for most types of work to have a strong jet which will carry considerable distances, quickly spraying large areas with moderately good coverage, rather than attempting to reach perfection over greatly reduced areas. Jet sprays with apertures 4/64 to 6/64 in. in diameter, with adjustable rotors, are available which will throw a jet a distance of 25 ft. or a finer spray for a smaller distance. Such a jet has the additional advantage of longer life than the very fine nozzles, which rapidly enlarge and require changing every day or two.

The power dusting-machines used for rubber are usually designed so that they throw the dust vertically or at least at an angle of 45 degrees. For field-crop work a machine is necessary which throws the dust horizontally, and it is very desirable to have, if possible, a flexible delivery tube. In regard to power and portability, these machines incorporate the features needed. Again in this case, the required types of machine are to be found in the market. With some, however, overheating takes place rapidly, and it is sometimes difficult to control the rate of dusting except over a certain very narrow range of applications.

Research into machinery for applying insecticides and fungicides is at least as necessary as research into the chemical products themselves. Though there are, no doubt, in existence types of machinery meeting the basic requirements, the need for improved output, greater sturdiness, maximum mobility, and ease of operation is still very great. Perhaps these improvements will come through evolution along the present lines. On the other hand, much interest is being shown in some countries, especially the U.S.A., in quite revolutionary principles, all of which involve the application of chemicals in the form of very fine particles, either dusts or fogs, distributed over long distances from the machine. Usually a powerful air-blast is used to direct the dust or spray, and in some cases at least high temperatures are used to prepare the fog. The

chief failings of many of these machines at present are their poor manœuvreability and their inability to direct the spray or dust, resulting in poor deposits and much waste of material.

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COMPOSITION OF WOODLAND SOILS AND WOOD ASH IN NORTHERN RHODESIA

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THE large copper-mining companies of Northern Rhodesia have been forced recently, by the inability of the railway to transport sufficient coal for their requirements, to utilize local wood as a supplementary fuel for power and for process steam. For fuel calculations and studies on the behaviour of the ash under various systems of wood firing it was necessary to obtain a careful and complete analysis of wood ash. While engaged on this work, the writers, who have long observed the beneficial effects of wood ash on the soils of Northern Rhodesia, felt that a brief report on the relation between composition of soil and of wood ash in this territory would be of interest to many engaged in tropical agriculture and forestry.

As in vast areas of the Central African Plateau, the forest cover of the copper-belt in Northern Rhodesia is almost entirely dominated by trees of the closely related genera Brachystegia and Isoberlinia. At the power plant of Rhokana Corporation wood is received on lorries in 4-ft. lengths, and sawn into 2-ft. lengths. A truly representative sample of local wood could accordingly be obtained by collecting small portions of sawdust daily for a period of several weeks. This large composite was thoroughly mixed, reduced in size by riffling to a 20-lb portion, which was all 'ashed' in a muffle to constant weight. The final 'ashed' sample of approximately 200 gm. was passed through a 100-mesh sieve and thoroughly mixed for the analytical work. It was found that the wood as received contained 39·9 per cent. moisture and 1·35 per cent. ash, giving 2·24 per cent. ash on the dry basis.

To obtain a composite soil sample as representative as that of the wood ash, a large number of soil samples were taken from the areas which supplied wood to the power plant during this period. These were dried, pulverized, thoroughly mixed, riffled, and a thoroughly representative sample finally secured for analysis. The sampling and analysis of the soil were carried out in accordance with the 1945 edition of *Methods of Analysis* of the Association of Official Agricultural Chemists [1].

Very little work has been reported on the soils of Northern Rhodesia, so that it is not possible to describe them under an international or even a national nomenclature. No soil analyses are presented in the only published ecological studies of this territory [2, 3]. The soils have generally a buff to orange colour, and they range from mixtures of clay and clay-sand to sandy soils. Usually they possess a horizon of ferruginous nodules in their lower levels. They are weakly acid, low in organic matter, generally deficient in bases, and usually unproductive. On the copper-belt they are heavily leached by the 40–50 in. of rainfall concentrated in 7 months of the year.

Over large tracts of Central Africa a primitive form of agriculture, termed 'chitemene', is practised by the natives. A small area is cleared, the trees piled and burned, the surface of the soil scratched with a hoe, and crops of maize, kaffir corn, millet, sweet potatoes, cassava, pumpkins, &c., sown in the wood-ash soil-surface. After several years the site is abandoned, the village as well as the garden is moved to a new location, and the bush in time is regenerated. In this system the trees are felled not only for clearing a patch of land but also to provide through their ash a seed-bed which the African has found by experience to give satisfactory crops for several years. The burning may, of course, also tend to loosen up the underlying soil and make some nutrients more readily available for plants. We believe, however, from the results of analysis, that the principal benefit is derived from the ash itself. Presumably the abandonment of the garden coincides with the exhaustion by leaching and cropping of plant-nutrients supplied by the wood ash. The analytical results on soil and wood ash are given in Table I.

TABLE I. *Analysis of Soil and Wood Ash from Northern Rhodesia Woodland*

Constituent	*Soil*	*Wood ash*
	per cent.	per cent.
SiO_2	79·26	33·70
Al_2O_3	8·95	2·21
CaO	0·05	24·30
MgO	0·53	7·30
Fe_2O_3	3·05	4·22
P_2O_5	<0·01	5·44
TiO_2	0·45	<0·01
SO_3	0·07	2·90
Mn_3O_4	0·05	0·54
CuO	0·02	0·87
Na_2O	1·02	5·40
K_2O	0·79	8·87
N	0·07	0·03
Loss on ignition	3·89	..
pH	6·3	12·7

Examination of Table I reveals the scientific basis for the native practice of 'chitemene' agriculture. The soils of this area are very deficient in many essential elements, particularly calcium, phosphorus, and potassium, but the dominant forest genera are evidently excellent collectors of these elements. When the wood is burned the ash supplies a large quantity of readily available nutrients for plant-growth. The concentration of magnesium and sulphur in wood ash is likewise noteworthy. The high copper-content of soil and wood ash is not unexpected in view of the inevitable distribution of traces of copper by wind and water over areas some distance from the great mining centres of Northern Rhodesia.

The soils are very low in organic matter and nitrogen. Owing to the native custom of setting fires in the bush annually in order that the game

may be seen, no accumulation of leaf-mould or forest litter occurs. It is interesting to observe that although leaves and grass vegetation under the trees are burned, the trees themselves are very resistant to fire. The solubility of wood ash and consequent ready availability of nutrients is indicated by the high pH when ash is moistened with water.

Although most mineral elements occurring in measurable quantities in this soil tend to concentrate in wood ash, silicon, aluminium, and titanium are much higher in the soil. The apparent insolubility of titanium compounds in soil solution, indicated by its virtual absence in this wood ash, is of interest.

Summary

The composition of woodland soils and wood ash in Northern Rhodesia indicates that the latter supplies an excellent source of many elements essential for plant-growth. On this fact rests the justification for the primitive 'chitemene' agriculture, wherein crops are sown in wood ash, practised extensively by natives in Central Africa.

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THE EGYPTIAN SHEEP: AN ATTEMPT TO IMPROVE QUALITY AND QUANTITY

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WITH PLATES 1, 2, 3

Introduction.—Judged by the criterion of total sheep-numbers or by that of the ratio of sheep to human population, sheep are relatively unimportant in Egypt. There are normally fewer than 2 million sheep in Egypt, or a ratio of about 1 sheep to 8 or 9 people; in Australia, for example, there are 16 sheep *per capita*. The improvement of Egyptian sheep is nevertheless a worthwhile project. The agricultural resources of Egypt, relative to the population dependent upon them, are so meagre that it is essential that the fellahin utilize the best agricultural methods, including the most efficient types of livestock, if they are to obtain even a fairly reasonable living from the land. Moreover, there appears to be so much room for improvement of the Egyptian sheep that a small expenditure of effort and money in that direction should pay relatively large dividends.

There are various breeds of sheep in Egypt, most of which are badly mixed, but the Ossimi, a white-wooled type, and the Rahmani, a brown-wooled type, are found in a fairly pure state. All Egyptian sheep are of the fat-tailed type. They are leggy and small, a mature ewe weighing 100 to 120 lb. The meat is lean and, in the fully grown animal, stringy. The wool, which is classed in the world markets as carpet wool, is coarse, almost straight, and void of grease. An average fleece weighs 3–4 lb. [1].

The Egyptian farmer maintains his sheep as cheaply as possible. They are fed no grain and are grazed largely on weeds and grasses remaining on the wheat, cotton, and maize fields after the crops are harvested. The farmer believes that further expenditure on his sheep would be uneconomical, and he is probably correct as they do not respond well to good care [2].

The only natural advantages of the Egyptian sheep are its hardiness and, by virtue of the energy which it stores in its tail, its ability to exist in an environment where the food-supply is uncertain. The same sheep is found throughout the desert and semi-desert areas of the Middle East and North Africa, areas to which it is obviously well adapted. It is equally obvious that it is not well adapted to the intensive agriculture of the Nile valley and Delta. It is the author's belief that once a more highly developed type of sheep is introduced into Egypt, the farmer will find it to his interest to give his flock more intensive care [2].

Improvement of the local breeds by selection over many years has been attempted by several workers in Egypt. However, as might be expected, the resulting improvement extended only within the genetical limitations of the type. The improvement was not sufficient to justify the farmer changing his methods of husbandry [2].

Previous introductions.—Mohamed Aly the Great, Ruler of Egypt and

founder of the present Egyptian Royal Family, made the first recorded introduction of foreign sheep into Egypt. He imported Merino sheep from France in order to create a local source of good-quality wool for the uniforms of his soldiers. The Merinos were crossed with Egyptian sheep, and in 1836 there were some 7,000 head of these sheep in Behera Province in the Delta area. Homont, in his book *L'Égypte sous Mohomet Aly* [3], calls the experiment a failure, which he attributes to the ignorance and carelessness of the people in charge of the animals rather than to the climate or other physical conditions subsisting in Egypt. However, we have not enough detailed information regarding this work to pass a scientific judgement upon it. The Royal Agricultural Society imported the Merino and other European breeds but apparently with no success. The late King Fouad introduced a Bulgarian breed of sheep on the Royal Estates; they were graded with Rahmani sheep with considerable success. The resulting sheep are somewhat fat-tailed, short-legged, and compact, but the wool starts black in the young animal and fades into brown and dark yellow in later life.

Present work.—The author was convinced that the only successful method of improving the local breed would be through grading them up by a suitable superior breed. While in Britain he had ample opportunity of examining the British breeds and obtaining first-hand information about them. It was essential to choose a more or less dual-purpose breed as the conditions in Egypt are not yet ripe to allow of the introduction of specialized breeds. A breed which produced good mutton was considered essential, as the Egyptians prefer mutton to all other meat. Thus the choice fell on the Suffolk. In 1940, two Suffolk rams were imported from England and the experiment described in this paper was started. Of the Egyptian breeds, the author chose the Ossimi, as its wool is white and the mutton equal to the best produced by Egyptian sheep. A description of the two breeds used in the experiment follows.

The Suffolk breed originated about 1800 in south-eastern England as a result of crossing the old Norfolk sheep with the Southdown; the former is known for its hardiness and good mutton, and the latter for its excellent mutton. The Suffolk (Plate I*a*) is hornless in both sexes, and is white with a black face; the ears are of medium length, the neck of moderate length and well set; the shoulders are broad, the chest deep and wide, and the back and loin are long, level, and well covered with flesh; the ribs are long and well sprung with a full flag; the legs are straight and covered with wool to the knees and hock but are clean and black below; the front legs are set well apart; the hind legs are well covered with mutton and the belly well covered with wool. The wool is moderately short and is of a close, fine fibre. An average fleece weighs 7 lb. A mature ram weighs about 250 lb. and a mature ewe 160 lb. Suffolk ewes are prolific, the average lamb crop approximating 135 per cent. [3, 4].

The Ossimi breed (Plate 1*b*) is named after the village of Ossim in Giza Province of Middle Egypt. It is the most popular and widespread of the Egyptian breeds. The body is narrow and shallow and carries a white, coarse, loose wool of medium length. The back is level but

narrow; the legs are long and spindly, and the head is reddish-brown and bare of wool. The tail is broad, round, and fatty; it ends with a twist which should not come below the hocks. The breed is horned in males and hornless in females.

Experimental

Of the two Suffolk rams imported from England, one died through an accident; the other was used in this experiment. The Ossimi ewes were selected at random from a flock kept on the Ministry of Agriculture's farm at Sakha in the Delta. This flock had been maintained on the farm solely for utilizing crop aftermath and was not outstanding in any way; it was chosen as representative of the breed, so that the results of the experiment might be applicable to the breed in general.

In order to observe the reaction of the Suffolk breed to the Egyptian environment, the ram was given no special care but was treated in the same manner as the Ossimi ewes. On arrival it was taken to the Animal Breeding Station at Sakha where it was fed with the Egyptian sheep and housed in a simple mud-brick shed.

Forty Ossimi ewes were chosen for mating with the Suffolk ram and 20 for mating with an Ossimi ram as a control. At the outset great difficulties were met with in getting the Suffolk ram to serve or even to approach the ewes. This unnatural behaviour appeared to be due to sexual shyness resulting from the new environment and the type of ewe. Attempts were made to stimulate him, including massaging and hormone injections.

After about 6 months the ram showed signs of sexual desire, which the author is inclined to attribute not entirely to the attempts at stimulation but to the orientation of the ram to his new environment. However, a new difficulty arose as the ram was not able to reach the ewe because of the broad tail. Shifting the tail of the ewe by the shepherd proved a failure, for the ram would not then approach the ewe. It was finally necessary to resort to docking about 50 mature ewes, and it was only then that mating was made possible. By then an entire year had elapsed since the arrival of the ram in Egypt. [In later experiments Suffolk rams were trained to mate the fat-tailed ewes and docking was no longer necessary.]

A castrated Ossimi ram was used to indicate the ewes in heat, and the latter were then taken to the ram for mating and the data recorded. The same method was followed with the Ossimi flock. All the ewes were tattooed and ear-ringed to assure correct recording.

The lambs were weighed on the day of birth,[1] at weekly intervals for the first month, at fortnightly intervals for the next 2 months, and thereafter at monthly intervals[2] until they were 6 months of age. The weekly changes in weight after the first month were established by interpolation. The lambs were always weighed at the same time of day.

[1] Hammond [6] recommends weighing the lambs on the third day after birth in order to allow time for drying. However, in Egypt's hot dry climate this seemed unnecessary and the weight was recorded a few hours after birth.

[2] In this way temporary environmental changes were eliminated.

Results

Effect of the Egyptian environment on the Suffolk ram.—The Suffolk ram lived in Egypt for more than 2 years in normal health. After its initial sexual shyness, its vitality much exceeded that of Egyptian rams. In October 1942 the ram died of inflammation and inflation of the pericardium. Although the ability of Suffolk sheep to tolerate the Egyptian environment cannot be definitely determined until much more evidence is available, experience with this ram affords no basis for presuming that the breed will not flourish in Egypt. Subsequent work by the author with Suffolk rams and ewes appears to be indicating a similar conclusion.

Effect of the Suffolk sire.—Fig. 1 and Tables 1 and 2 show that the average weight of the offspring of the cross was greater than that of the Ossimi throughout the period. At birth the average weight of the cross was 30 per cent. greater than that of the Ossimi. As the ewes in the control flock averaged 106 lb. compared with 105 lb. for those mated to the Suffolk ram, the increased weight of the offspring of the cross must be attributed entirely to the effect of the sire.

TABLE 1. *Average Weight of the Cross-breed (Suffolk × Ossimi) (19 lambs)*

Age in weeks	*Mean weight (lb.)*	*Standard deviation*	*Coeff. of variability (%)*
At birth	9·1	2·37	26·0
4	24·0	4·71	18·62
8	37·0	6·41	17·32
12	55·0	8·82	16·03
16	74·0	9·96	13·45
20	89·0	11·64	13·0
24	94·0	13·0	13·8

TABLE 2. *Average Weight of the Pure Ossimi (13 lambs)*

Age in weeks	*Mean weight (lb.)*	*Standard deviation*	*Coeff. of variability (%)*
At birth	7	1·4	20·0
4	18	3·31	18·4
8	29	3·33	11·8
12	42	6·16	14·6
16	54	9·9	18·3
20	62	11·36	18·3
24	67	13·1	19·5

The difference between the average weight of the two lots of lambs increased with their age. At the end of the 6th month the lambs from the cross averaged 40 per cent. heavier than the Ossimi lambs. As is indicated in Table 3, these differences are statistically significant.

Rate of Growth.—The lambs from the cross reached a satisfactory weight for butchering in substantially less time than was required by the Ossimi lambs. For example, the cross lambs weighed 55 lb. at the

TABLE 3. *The Differences, and their Degree of Significance between the Average Weights of the Cross-breed and the Ossimi*

Age in weeks	*Difference (lb.)*	*Level of significance 3 × (standard error)*
At birth . . .	2·1	1·98
4 . . .	6·0	4·23
8 . . .	8·0	5·28
12 . . .	13·0	7·92
16 . . .	20·0	10·8
20 . . .	27·0	12·33
24 . . .	27·0	14·1

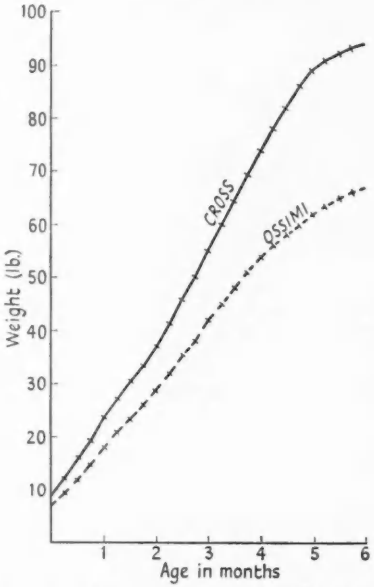


FIG. 1. Growth curves of Ossimi and crossbred Suffolk–Ossimi lambs.

12th week, whereas the Ossimi lambs attained this weight at the end of the 16th week. The advantage of the faster rate of growth, both in decreased costs of husbandry and in the superior quality of the meat from younger animals, is obvious.

The two important aims achieved were a substantial increase in the weight combined with superior quality of the mutton sold.

Fig. 2 shows that the rate of growth of the cross is much superior, in all stages of age, to that of the Ossimi. The cross increases in the first week by 3·3 lb., whilst the respective increase in the Ossimi is only 2·4 lb. In the 13th week the increase is 5 lb. in the cross and 3 lb. in the Ossimi. In the 20th week the rate of growth of the cross decreases to 2 lb., until it becomes only 1 lb. per week by the 22nd week, whilst the rate of

growth of the Ossimi begins to decrease in the 17th week to 2 lb. and afterwards to 1 lb.

Two cycles of growth are observed in both the cross and the Ossimi. The first cycle begins in both of them at birth and ends at the 5th week. In the 10th week the rate begins a new upward trend till it reaches its maximum in the cross in the 13th week, and in the 12th week in the Ossimi. Then the rate of the Ossimi begins to decline at a quicker pace than that of the cross. This shows that there is a time-lag: the Ossimi

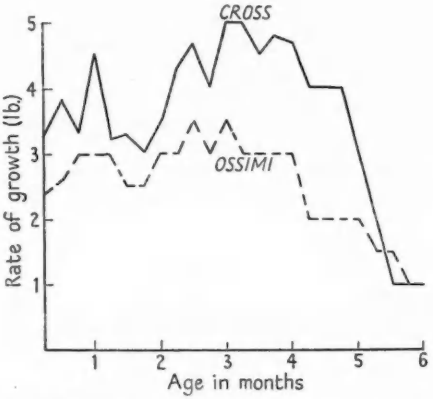


FIG. 2. Rate of growth of Ossimi and crossbred lambs, weighted for sex differences.

begins to increase a week later than the cross, and to decrease a week earlier. At the 6th month, both of them assume a uniform rate of growth of 1 lb. per month.

As a general rule we should keep our sheep as long as they show profit, i.e. every differential increase in weight is worth more than the cost needed to produce this increase. Thus the optimum time for selling off the sheep is when the rate of growth begins to decrease below the level of the cost of production. Fig. 2 confirms the fact that the cross sheep are more profitable to keep than the Ossimi sheep; they also reach the optimum time of selling at a younger age than the cross, i.e. the turnover of capital is quicker in them than in the Ossimi.

The common method of expressing growth in pounds per day or week is simple and usually quite satisfactory. But in our study the decisive factor in comparing the growth of the cross and the Ossimi is the potentiality of growth as indicated by the relative rate of growth because it represents the instantaneous true rate rather than the average indicated by the absolute rate of growth.

Fig. 3 shows the course of the increase in the natural logarithm of the weight; the slope at any point shows the relative rate of increase, which falls off perceptibly with increasing age, up to the 6th month when it almost becomes nil in both groups. The relative rate of growth in the

cross is greater than in the Ossimi. Furthermore, the increase in the relative rate of growth in the Ossimi decreases at a quicker rate than in the cross, otherwise the two curves would have been parallel.

This can be made clearer by obtaining the actual rate of the change in the relative rate of growth; this latter, considered in relation to age, is shown in Fig. 4, in relation to weight in Fig. 5. Both methods of approach are really necessary in studying the phenomenon of growth.

Fig. 4 shows that the relative rate of growth continuously decreases, especially in the first months, when the decrease is very quick; it also

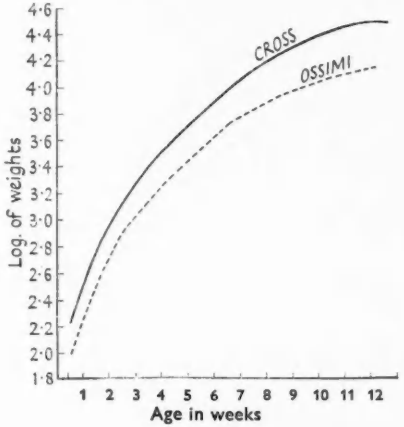


FIG. 3. Relative growth curves.

affirms the above-mentioned fact, viz. that the relative rate of growth of the cross is superior to that of the Ossimi. Though the experiment lasted for only 6 months, by computing the equation of the curve it was possible to extend the curve up to the 10th month, when the relative rate of growth almost faded out for both of the two groups.

The other way of approach, by considering the relative rate of growth in relation to weight, is also important. Here the two groups are always compared at the same age, and so the effect of age is equal in both of them. Thus, in Fig. 5 the great difference between the cross and the Ossimi is shown very clearly. The weekly weights of the Ossimi fall nearer to each other more quickly than in the cross, because the difference between each two successive weekly weights is much smaller in the Ossimi than in the cross. Furthermore, the relative growth-rate of the Ossimi decreases quicker than in the cross till it almost vanishes when the weight reaches 70 lb., whilst this does not happen in the cross till its weight reaches 95 lb.

Degree of Uniformity.—The degree of uniformity, as shown by the coefficient of variation, was found to be greater in the cross throughout all stages of growth. As the cross lambs grow in age, they become more and more similar in weight in a quicker way than in the Ossimi. At the

24th week, the coefficient of variation is 13·8 per cent. in the cross, (Table 1), whilst it is 19·5 per cent. in the Ossimi at the same age (Table 2).

At the optimum time of sale, i.e. the 20th week, the coefficient for the cross is 13 per cent., whilst at the optimum time of sale in the Ossimi,

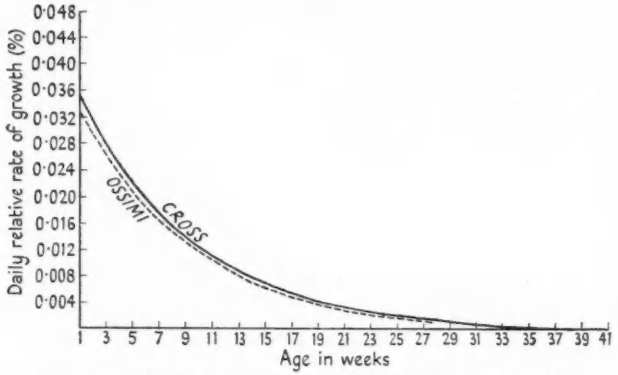


FIG. 4. Relation between age and relative rate of growth.

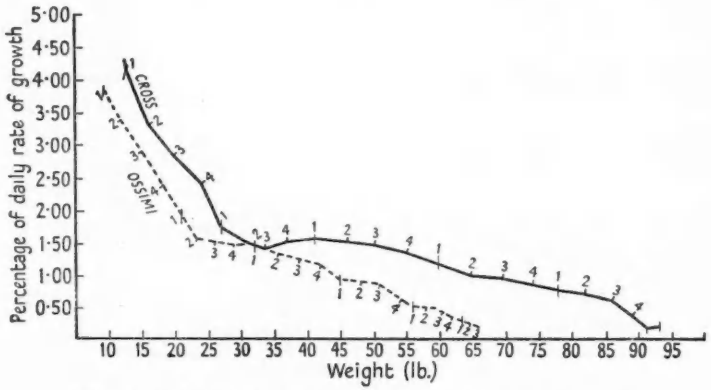


FIG. 5. Relation between weight and relative rate of growth.

the 16th week, it is 18·3 per cent. This means that the degree of similarity at the time of sale is greater in the cross than in the Ossimi. This is due to the resulting homozygosity in the first generation as an outcome of the crossing that was done. This result is certainly of great practical and commercial value in breeding and selling off the sheep for slaughter.

Effect of sex.—Fig. 6 and Table 4 show that the average weight of the male in the cross is greater at birth than that of the female by 2 per cent. At the 6th month the difference becomes 18 per cent. The Ossimi gives a different result (Fig. 7), the female is greater in weight than the male

TABLE 4. *Weights (lb.) of Male and Female Crossbreds*

Age in weeks	*Female weight (average)*	*Male weight (average)*	*Weight of male as % of female*
At birth . . .	9·0	9·2	102
4 . . .	22·0	25·5	106
8 . . .	35·0	38·0	108
12 . . .	51·0	58·0	114
16 . . .	68·5	77·5	113
20 . . .	82·0	95·0	115
24 . . .	85·0	100·5	118

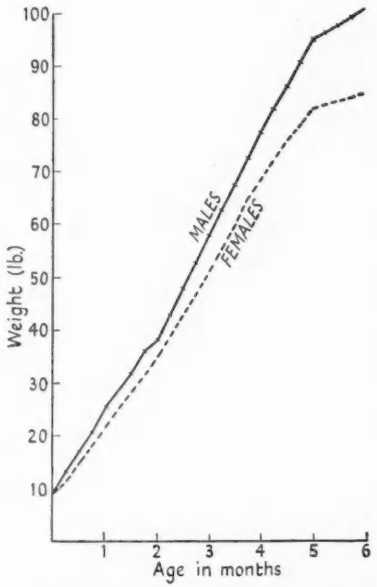


FIG. 6. Growth curves of the crossbreds (males and females).

up to the 3rd month, after which the average weight of the male begins to exceed that of the female. The difference between their weights at the 6th month is about 10 per cent. Thus the superiority of the males over the females is greater in the cross than in the Ossimi. This result is of great importance to the breeder who keeps the females for breeding and sells the males to the butcher.

Effect of the dam.—Hammond [6] has pointed out that 'while the ram can only affect the weight of the offspring by means of its genetic characters, the ewe is able to influence the weight of the lamb by nutritional conditions as well. The nutrition of the young can be affected by the ewe before birth through uterine nutrition, and after it through

the milk supply. . . . Failing Mendelian analysis, the best means of showing whether the ewe affects the weight of its offspring by genetic means is to see if the weight of the ewe is correlated with that of the lamb it produces.'

In this experiment the ratio of correlation in the cross is $0{\cdot}61 \pm 0{\cdot}127$, which means that there is a moderate positive correlation between the dam and its progeny. On this basis the breeder is recommended to choose for breeding the ewes whose weights are high relatively to their

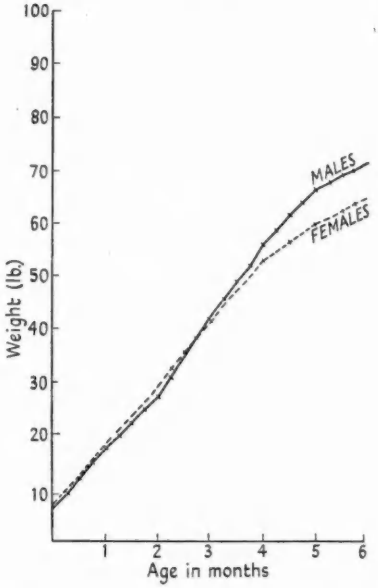
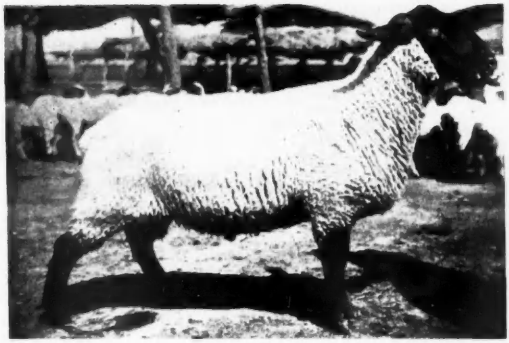


FIG. 7. Growth curves of the Ossimi (males and females).

age. Further, it was noticed that in some cases the weight of the twin was equivalent to the weight of the singlet, which makes the genetical effect of the dam obvious, as it is unreasonable to attribute the big weight of the twin to nutritional factors.

Inheritance of horns.—The Ossimi males have big curved horns, but the females are hornless. When the Ossimi females were mated with a Suffolk sire, all the males (20) of the progeny had horns, whilst the females were hornless. This result emphasizes in a preliminary way that this character is dominant in the male and recessive in the female. It is hoped that further experiments will throw more light on this point.

Mutton.—The general body-confirmation of the cross (Plate 1*c*) was much more similar to the mutton type (Plate 1*a*) than to the Ossimi type (Plate 1*b*), as shown clearly in the photograph. The body was wide, deep, and with full quarters. A closer study of the genetical behaviour will be tackled quantitatively later.

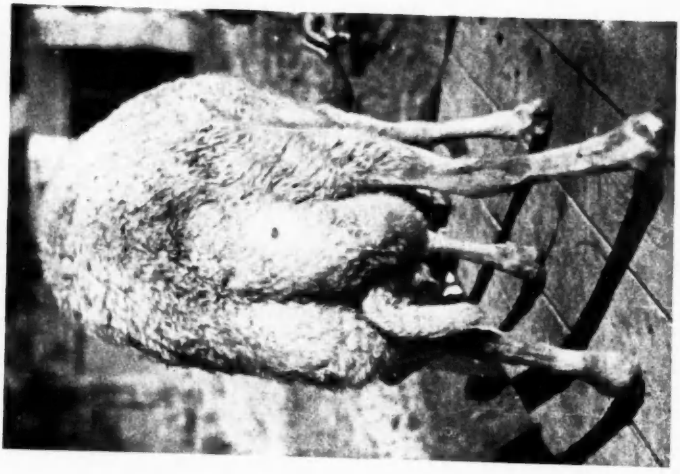


(*a*) Suffolk ram

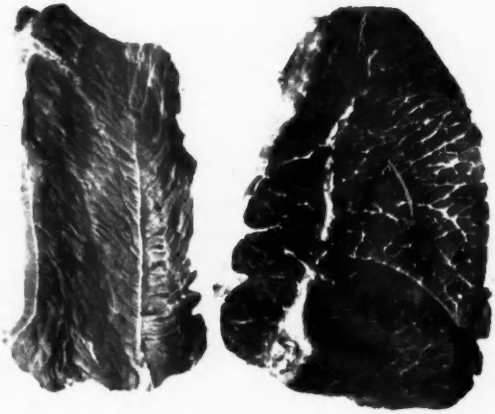
(*b*) Ossimi ram

(*c*) Cross

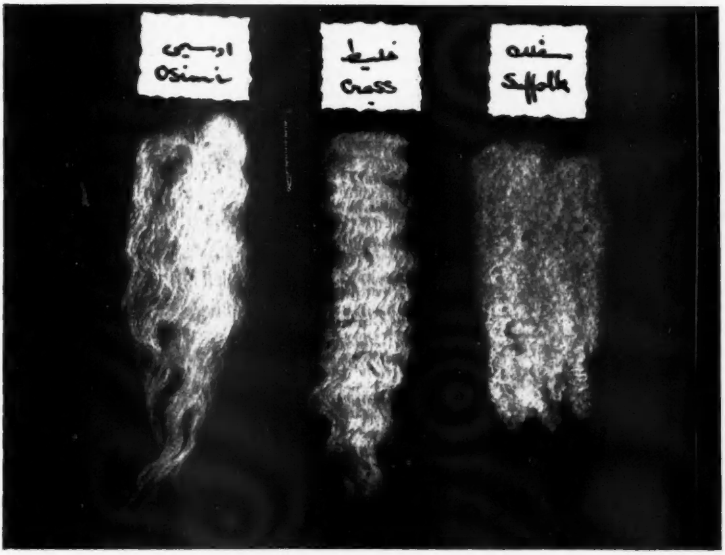
(*b*) Cross



(*a*) Ossimi



(*a*) Cross-section of muscle
Left, Ossimi: *right*, Cross



(*b*) Wool
Left, Ossimi: *centre*, Cross: *right*, Suffolk

The broad, fat tail, characteristic of the Ossimi breed (Plate 2*a*), and in fact of almost all the Egyptian sheep, has disappeared in the cross (Plate 2*b*); instead, a thin long tail of the Suffolk type appeared in all the progeny. This seems to indicate that the broad fat-tail character is recessive; an F2 is being produced to test this hypothesis. Further, the quality of the mutton of the cross (Plate 3*a*) was found to be marbled, taking this important character from the Suffolk sire. This character is therefore either partially or completely dominant.

Thus, this experiment has led to the great improvement of the mutton qualities. First, the broad fat tail is useful only under desert conditions as a food store which can be utilized in lean seasons. But in the valley, where food is much more abundant, it is of little value. Besides, it is a source of inconvenience for the ram during breeding times, and when the sheep are grazing it conduces to the accumulation of dirt and development of maggots. The tail is sold as a source of cooking-fat at a cheaper price than that of the meat; if involved in the mutton itself, it would attain the same price if not higher. The weight of the broad tail of the Ossimi was found to be 4·5 lb. and that of the tail of the cross 0·25 lb.

Wool.—The weight of the fleece did not exceed 3 lb. in the Ossimi and was never below 4 lb. in the cross. The fleece of the cross was compact as compared with the open type of the Ossimi. From the point of view of quality, the wool of the cross was much superior to that of the Ossimi. It was fine, greasy, wavy (Plate 3*b*), and strong. The wool extended to the belly, unlike in the Ossimi (see Plate 1 above). When the cross lambs were born, the colour of the coat was solid dark brown, but it gradually faded into bright white except the head and the legs, which remained dark brown. The pure Ossimi lambs when born had a white coat with a brown head and white legs; but there was no change in colour as they grew older. This character of being born coloured and then turning white (except the extremities) is obviously inherited from the Suffolk sire.

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THE PROGENY TESTING OF DAIRY BULLS

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ONE of the most important principles in breeding dairy stock is that the breeding policy must take both sexes into consideration. Although by dint of the number of its progeny the sire exercises an overwhelming influence upon a herd in which he is employed, in individual cases both the dam and the sire are of equal importance. Unfortunately, there is at present no direct method of measuring the performance of a male animal. There exists, however, general agreement that the progeny test of a bull provides a useful guide for the purpose of establishing its breeding value. It reveals to some extent the animal's genetic constitution. In modern breeding practice such knowledge is essential and efforts should be made to include progeny-testing of bulls as a routine measure in all pedigree herds.

Several methods of progeny testing have been suggested. The methods based on a dam–daughter comparison are generally considered more satisfactory than others. There are several of these, and they differ mainly in the manner in which they present the records. Some of the methods are described and discussed below, and so are some of the difficulties inherent in progeny testing.

The records of a Dairy Shorthorn bull, Kingsthorpe Fidgetty 3rd (K.F. 3), are used by way of illustration. This bull has been used in the N.I.R.D. herd during the years 1923–34 and produced 210 calves, 101 of which were heifers and 109 bulls. The first difficulty in investigating the transmitting ability of a bull occurs at this juncture. Only about half of the bull's progeny—the females—or rather their milk yields, provide the necessary material for evaluation. Furthermore, out of 101 heifer calves born, only 52 daughters of K.F. 3 completed their first lactation. The reasons for disposal of the 49 heifer calves before they were able to complete a lactation are given in Table 1. It is evident from these figures that

TABLE 1. *Fate of 101 Heifer Calves—Daughters of K.F. 3*

Born dead	10
Sold before first calving	12
Sold, reactors to TB and abortion tests	9
Sold before end of 1st lactation, poor milkers	13
Accidents	2
No reason recorded	3
	49
Completed 1st lactation in N.I.R.D. herd	52
	101

only about one-quarter of the progeny can be considered in evaluating the bull's breeding qualities. This illustrates the difficulties inherent in collecting satisfactory material for a progeny test. Unless the breeder knows the full facts included in Table 1, and unless he is able to view the

results of the progeny test in the light of these figures, he cannot assess the real value of the bull.

The dam–daughter comparison can be made by a statistician, who will be able not only to assess the value of the bull as exhibited in the available records, but also to indicate how accurate his assessment is. For practical purposes, however, there is no need to treat the data mathematically. A graphic or tabular presentation will prove sufficient; a diagram or a table will enable the breeder to judge at a glance the productive ability of the bull.

Inheritance grid method.—This method is illustrated in Fig. 1. Each dot on the diagram represents either the milk yield or any other variable, both of the dam (scale on the horizontal axis) and of the daughter (scale on the vertical axis). The graph is so designed that when the records of dam and daughter are equal, the dot will fall on the diagonal line. When the daughter's production exceeds that of her dam the dot will lie above; when it recedes it will appear beneath the diagonal line. An average for all the dams and daughters is indicated by a cross.

The position of the dots within the diagram indicates the scale of production of both dams and daughters. If, for example, the majority of the dots are placed in quadrant B of the diagram, the production of both the dams and daughters was high; if the concentration of dots is in quadrant D, the dams were high producers but their daughters low ones.

The distribution of the dots also indicates the genetical purity of the breeding material: scattered dots indicate heterozygotic qualities of the breeding stock, compact dots, homozygocy. When scattered horizontally the genetical 'impurity' is connected with the dam; when vertically it relates to the sire.

A rather recent development is the replacement of the diagonal line by a 'dividing line' (Fig. 1B), which is intended to indicate a desirable average quality of a bull. Thus, if the dots lie above the line it will indicate a superior bull, whilst if they lie below, an inferior bull, in comparison with the arbitrary average. The 'dividing line' is based on the principle of intermediate inheritance. Assuming that the bull tested possesses the ability to produce daughters with 8,000 lb. milk yield, the actual milk yield of the daughters will depend on the production ability of their dams. If the bull is mated with a cow of 8,000 lb. capacity, their daughters will be producing the same quantity, but if he is mated to a cow of only 5,000 lb. capacity, the yield of their daughter will average 6,500 lb. Similarly, if the bull is mated to 11,000 lb. cows their daughters will average 9,500 lb. In practice this means that the daughters of a good bull who was mated to very high-class females need not surpass or equal the high production of their dams to prove the quality of the bull.

It has been suggested with a view to introducing further improvements into the inheritance grid that each dot be marked with a number (Fig. 1C) and that a list be made out stating the names of the dam–daughter pairs with corresponding numbers. This will meet the criticism that the method allows only for general judgement upon the quality of the bull, without supplying the breeder with information as to what animals are responsible for the lesson to be drawn from the diagram.

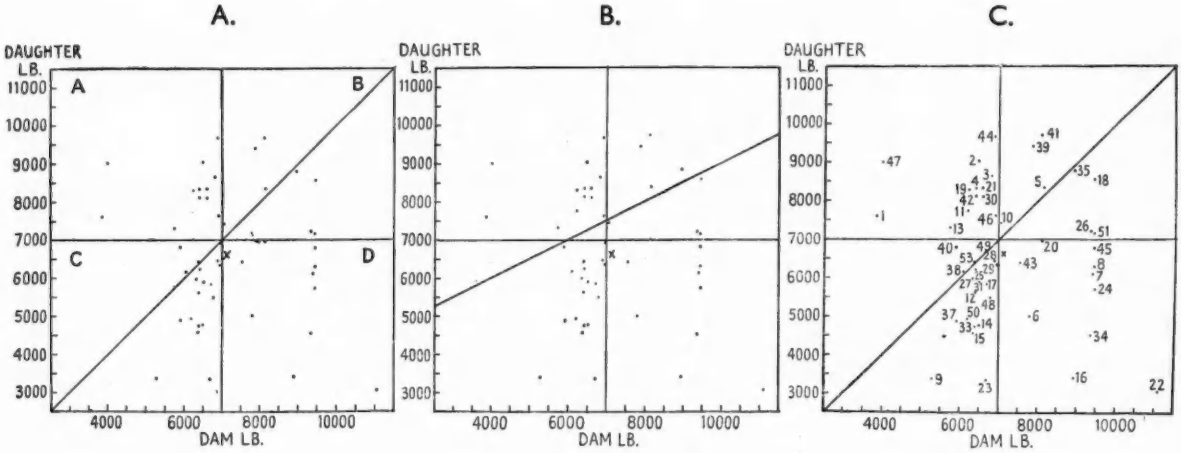

FIG. 1. Inheritance grid.

No.	*Dam*	*Daughter*
1	Wisdom	Wisdom 2
2	Fillpail 5	Flora 4
3	Cherry 3	Peach 2
4	Flora, &c.	Flora 5

Inheritance-curves method.—For dam–daughter comparisons within one herd the curvilinear presentation of records appears to be most useful. It gives a general view of the bull's activity in a diagram (Fig. 2A)

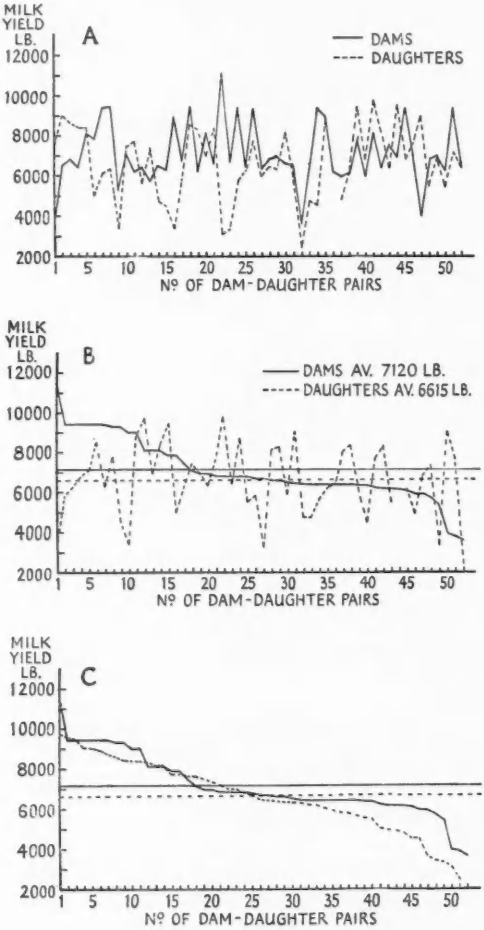

FIG. 2. Inheritance curves.

in which milk yield, or any other variable, of both dam and daughter is entered in chronological order of calving on one vertical line. Two curves are then drawn, one connecting all the 'dam points' and the other all the 'daughter points'. Unless one is dealing with a very homozygotic herd the diagram will, however, not be clear and will prove difficult to interpret. To get over this difficulty it has been suggested that

instead of entering the pairs in chronological order of calving, the dams could be grouped according to their milk yield in descending order, and the milk yields of corresponding daughters inserted above or below their dams (Fig. 2B). The greatest advantage of this method lies in the fact that at a glance the breeder is able to assess the suitability of a bull for a herd of cows to which he was or is going to be assigned. For example, diagram B in Fig. 2 shows that although K.F. 3 was able to maintain and even surpass the milk yield of his daughters as compared with that of their mothers, in the low and medium classes of cows, his genetical capacity was not sufficient to make his daughters improve upon, or even attain, the yield of the high-yielding dams.

As a rule it is possible to assess the value of the bull on the basis of a diagram, but none the less it is desirable to have the average figures for both the dam and the daughters indicated either graphically or numerically (Fig. 2B). A list of dam–daughter pairs taken into consideration could be appended to the diagram for the same purpose as in the grid method.

It has been suggested that in order to get a ready guide to the value of a bull by exhibiting the range of its potentialities, and illustrating in what proportion the various yields contributed to the average, a further diagram might be constructed in which the milk yields of both dams and daughters are arranged in declining order (Fig. 2C).

Performance-card method.—This method of presenting the dam–daughter comparison is illustrated in Fig. 3. In it the dam's name appears in a quadrangle and the name of the daughter is entered without a frame on the same horizontal line. Each dam and her daughter sired by the particular male occupy a horizontal line, and their place on it is determined by their respective milk yields, or by any other variable. Thus, all daughters appearing on the right-hand side of their dams indicate improvement brought about by the sire, whilst those on the left side decline. It is advisable to arrange the dams according to their yield, instead of entering them in order of calving. The average yield of dams and daughters is shown by two vertical lines, and the calculated 'genetical value' of the bull, based on the principle of intermediate inheritance, is also entered. The sponsors of this method see a big advantage in the fact that all daughters of a dam can be seen at a glance, whilst the methods previously described dealt with only one generation.

Tabular method (*Fig. 4*).—The advantage of the tabular method of presentation of the dam–daughter comparison lies in the fact that with a comparatively small effort all the required data, irrespectively of the number of variables, are presented together. They are simply copied from the herd-book. On the other hand, the actual comparison requires a more careful and time-consuming study. Particulars of records of the dam and her daughter are entered in the table in the same horizontal line, and by underlining, or other means, it is shown which of the two brought forth better results in a particular sphere of production. Thus, without going into any details one is able to say, that, for example, out of 25 dam–daughter pairs the milk yield of 15 dams was superior to that of their respective daughters, but only in 10 cases did the daughter's yield

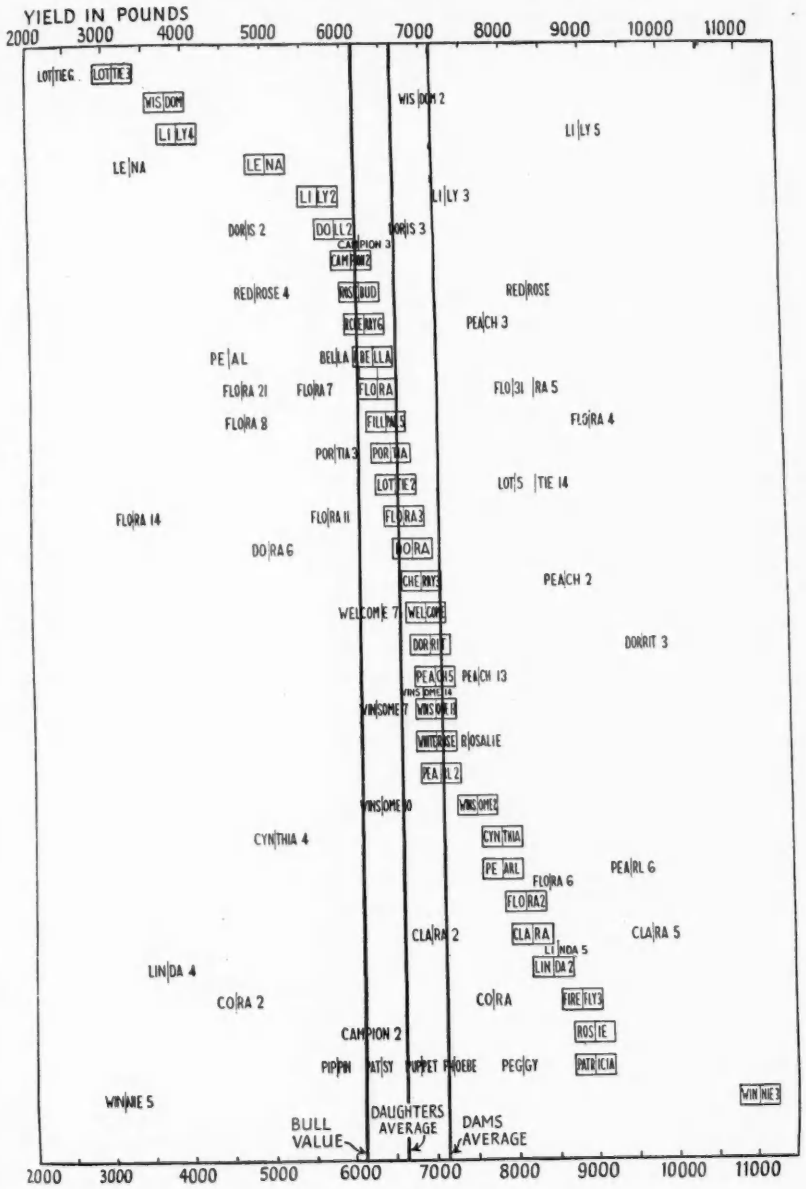

FIG. 3. Performance card.

exceed that of the dam. Each dam–daughter pair can be entered into the table as soon as the record of the daughter is completed. No prior segregation of records is necessary.

Milk yield and fat-content.—Having decided upon the method of progeny testing the breeder must realize the need of taking both the milk yield and its fat-content into consideration. Diagrams A and B of Fig. 5 show clearly that on the average K.F. 3 slightly lowered the yield of milk, but increased the fat-content of milk of his daughters. It would therefore be misleading to attempt to evaluate a bull on the basis of only one of the factors. On the other hand, two methods of combining the two factors: (*a*) by expressing lactation-fat yield (Fig. 5C), or (*b*) by converting the yield to a 4 per cent. fat-corrected milk, FCM (Fig. 5D), a method widely applied in America, are useless from the point of view of a breeder of dairy cattle, because the two factors are transmitted independently and therefore require individual attention. Both the last-mentioned methods of expressing production, however, are quite useful when the economic value of the animal is under review.

Number of dam–daughter pairs required.—There is a well-founded tendency to use as few dam–daughter pairs as possible for progeny testing. The less daughters are required the sooner the value of a bull can be established, and the advantages of an early evaluation of a bull are obvious. There is, however, a minimum of dam–daughter pairs, which if disregarded makes the progeny test unreliable and often misleading. What this minimum is is still a moot point admitting no definite answer. The following example will prove the importance of this aspect of the problem and should help the reader to form his own judgement upon it.

The progeny test of the bull K.F. 3 has been carried out on the available records of 52 dam–daughter pairs. With such a large number a fair indication of the value of the bull has been obtained, in spite of the considerable variability of the data. In practice, however, at the time when a test is carried out, the number of completed records will be much smaller. In Fig. 6 the diagram A dealing with milk yield shows clearly that when uncorrected first-lactation records have been used, at least 20 dam–daughter pairs were required to arrive at a true picture of the value of the bull as transmitter of milk yield (compare with Diagram B in Fig. 2). Diagram A of Fig. 6 also shows that an insufficient number of dam–daughter pairs may lead to a completely wrong judgement on the value of the bull. Diagram B in Fig. 6 suggests that as far as fat-content is concerned, the number of dam–daughter pairs is not of primary importance; but even here the more pairs are taken into account the more reliable are the results.

The advantage of using standardized records and production-ability indices[1] for progeny testing are obvious. Standardization of records will, however, not reduce to any extent the number of dam–daughter pairs required for the progeny test, but it will conduce to accuracy, and

[1] A paper on standardized milk records and production-ability indices is being prepared for publication.

	Dams						Daughters					
	Name of cow	*Lactation*	*Milk yield lb.*	*Fat content %*	*Fat yield lb.*	*4% Fat-corrected milk yield lb.*	*Name of cow*	*Lactation*	*Milk yield lb.*	*Fat content %*	*Fat yield lb.*	*4% Fat-corrected milk yield lb.*
1	Wisdom	1	3,844	3·80	146·1	3,729	Wisdom 2	1	7,604	3·89	284·3	7,241
2	Fillpail 5	1	6,499	3·66	238·3	6,174	Flora 4	1	*9,031*	*3·87*	*349·5*	*8,848*
3	Cherry 3	1	6,833	3·79	259·8	6,630	Peach 2	1	*8,678*	*4·18*	*362·8*	*8,721*
4	Flora	1	6,409	3·40	217·9	5,832	Flora 5	1	*8,390*	*3·68*	*308·8*	7,987
5	Flora 2	1	8,129	*3·82*	310·5	7,909	Flora 6	1	*8,378*	3·79	*317·5*	*8,114*
6	Cynthia	1	*7,876*	3·69	*290·6*	*7,432*	Cynthia 4	1	5,002	*4·73*	236·6	6,340
7	Rosie	1	*9,431*	..	..	..	Campion 2	1	6,110	4·02*	245·6*	6,129*
8	Patricia	1	*9,475*	*4·09*	*387·5*	*8,933*	Patsy	1	6,302	3·82	240·7	6,132
9	Lena	1	*5,301*	3·66	*194·0*	*5,030*	Lena 2	1	3,378	*3·71*	125·3	3,231
10	R. White Rose	1	7,048	3·78	266·4	6,815	Rosalie	1	*7,423*	*4·06*	*299·0*	*7,422*
11	R. Cherry 6	1	6,236	*3·84*	239·5	5,999	Peach 3	1	*7,744*	3·34	*258·7*	*6,978*
12	Flora	1	*6,409*	3·40	217·9	*5,832*	Flora 7	1	5,613	*4·10*	*230·1*	5,697
13	Lily 2	1	5,740	*3·91*	220·2	5,556	Lily 3	1	*7,362*	3·43	*252·5*	*6,733*
14	Fillpail 5	1	*6,499*	3·66	*238·2*	*6,174*	Flora 8	1	4,765	*3·76*	179·2	4,594
15	R. Bella 3	1	*6,360*	3·89	*247·6*	*6,259*	Peal	1	4,542	*4·90*	222·6	5,156
16	Linda 2	1	*8,956*	3·60	*322·3*	*7,705*	Linda 4	1	3,416	*4·28*	146·2	3,660
17	Flora 3	1	*6,706*	3·99	*267·6*	*6,696*	Flora 11	1	5,833	*4·08*	238·0	5,903
18	Patricia	1	*9,475*	*4·09*	*387·5*	*8,933*	Peggy	1	8,565	3·69	316·1	8,096
19	Rose Bud	1	6,227	3·96	246·6	6,190	Red Rose	1	*8,311*	*4·41*	*366·5*	*7,730*
20	Clara	1	*8,130*	4·13	*355·8*	*8,288*	Clara 2	1	6,974	*4·38*	305·5	7,375
21	Lottie 2	1	6,592	3·63	239·3	6,216	Lottie 4	1	*8,385*	*3·85*	*322·8*	*8,184*
22	Winnie 3	1	*11,108*	*3·99*	*443·2*	*10,428*	Winnie 5	1	3,067	3·82	117·4	2,984
23	Flora 3	1	*6,706*	3·99	*267·6*	*6,696*	Flora 14	1	3,345	*4·13*	138·1	3,410
24	Patricia	1	*9,475*	*4·09*	*387·5*	*8,933*	Pippin	1	5,763	4·08	235·1	5,832
25	Flora	1	*6,409*	3·40	217·9	5,832	Flora 15	1	6,215	*4·32*	*276·4*	*6,531*
	No. of Dams superior to Daughters	..	15	7	13	13	No. of Daughters superior to Dams	..	10	17	11	11
	Average	..	*7,275*	3·80	*276·4*	*6,843*	Average	..	6,407	*4·01*	256·9	6,361

FIG. 4. Inheritance table.

* Not included in the average—corresponding dam's record not available.

Figures in *italics* are higher than the corresponding ones on the other side of the table.

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make possible interpretation of the test independently of the material on which it has been based.

Care in selection.—The importance of using every available record of a daughter of a bull whose breeding quality is to be assessed has already been stressed. Evaluation of a bull on the basis of selected material might be completely misleading, and especially so when the data are not standardized. Using the data of K.F. 3 as an illustration, two lots of 15 dam–daughter pairs have been selected. The records of one lot testify to the high value from the point of view of improving the milk yield of the

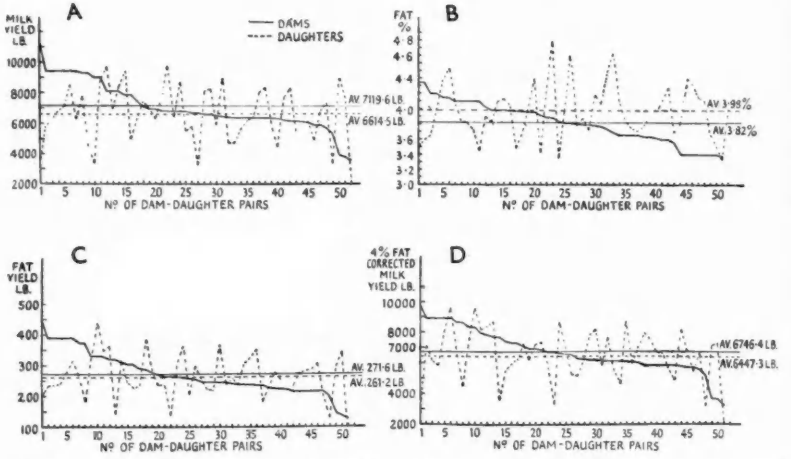

FIG. 5. Inheritance curves; A, milk yield; B, fat-percentage; C, fat yield; D, milk yield converted to 4 per cent. fat.

herd (dams average = 6,801 lb., daughters average = 8,567 lb.), whilst the records of the other lot lead to an opposite conclusion (dams average = 8,995 lb., daughters average = 6,139 lb.). The inference is obvious: a correct assessment of the value of a bull based on records of its progeny is impossible unless every record of every daughter is included in the analysis. It would be inapposite, to say the least, to state, for example, that the bull K.F. 3 produced 15 qualified daughters (although such statement is true), without mentioning that the 15 daughters have been especially selected, and that in general the bull tended to lower rather than to improve the milk yield of its progeny.

Records for use in progeny tests.—With standardized records it will become immaterial what lactation records are taken as a basis for calculating the value of the bull. Owing to the need for speed, the production-ability indices based on the first lactation records for a minimum of dam–daughter pairs will be used to provide a tentative value. This will eventually be replaced by a final value calculated from the average production-ability indices for all dam–daughter pairs. To increase the accuracy of the test, where more than one lactation record is available

for both dam and daughter these indices should be calculated as an average for as many lactation records as possible. In this case it is necessary to take the same number of lactations for the dam as for the daughter in order to avoid an additional source of error.

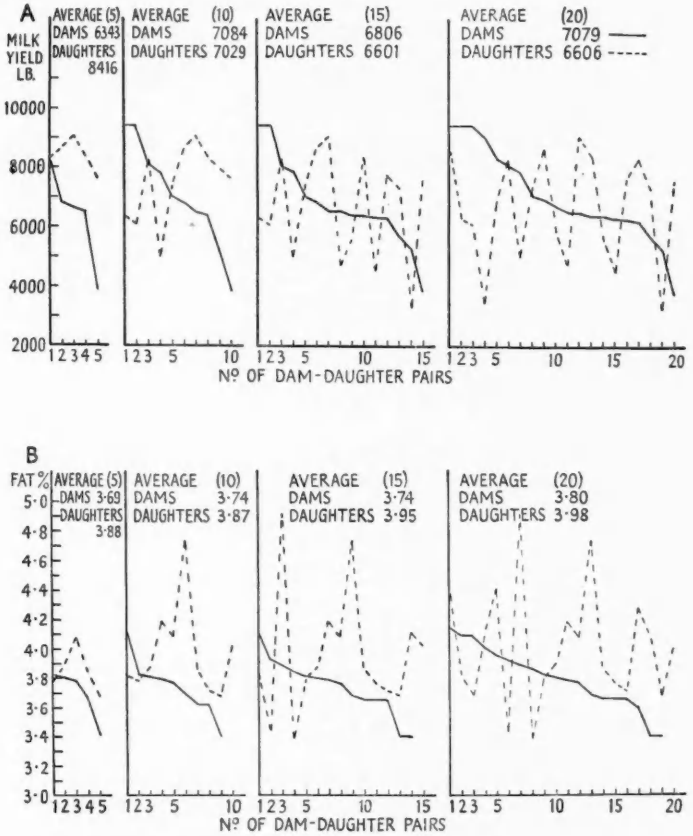

FIG. 6. Effect on number of daughters available for a progeny test.

It is obvious, on the other hand, that by waiting for more records to accumulate the number of dam–daughter pairs with two, three, or more lactation-records for both animals will undoubtedly decline, often as a result of selection exercised by the breeder. Thus, for bull K.F. 3, only 25 out of the original 52 dam–daughter pairs have completed three lactation-records; 27 dam–daughter pairs had to be discarded. From Table 2 it is evident that a selection according to merit has been practised to a considerable extent. Incidentally, such a selection can be expected to be practised in a well-managed herd. A progeny test carried

out on the selected 25 dam–daughter pairs, using their first-lactation records as the basis, will obviously be unreliable and, as shown in Fig. 7, diagram A, in the case of K.F. 3, misleading. By using records based on three lactation averages instead of on the first-lactation record (Fig. 6, diagram B) much more correct results are obtained.

TABLE 2. *Cause of Disposal of K.F. 3's Daughters after Completing their First Lactation.*

Disposal during 2nd lactation:	Poor milkers	6
	Abortion reactors	1
	Accident	1
Disposal during 3rd lactation:	Poor milkers	4
	Abortion reactors	8
	Udder trouble	2
	Accident	1
		23
Animals with incomplete dam's record		4
	Total	27

In conclusion, it appears that a progeny test is best carried out on production-ability indices based on standardized lactation-records of all the daughters of the bull whose breeding qualities it is intended to test. The accuracy of the test can be increased by using production indices based on more than one lactation-record, provided such data are available for both the dam and the daughter.

Progeny-test 'abstract' and its interpretation.—As the progeny test has been found to be the most suitable method at our disposal for evaluating the breeding qualities of a bull it is essential to standardize the method of application. The following formula, which takes into account the lessons drawn from the preceding paragraphs, will, it is suggested, provide all the necessary information and allow for a proper interpretation of the results of the test. (The formula is illustrated on the example of K.F. 3.)

Kingsthorpe Fidgetty 3rd[1]	Shorthorn[2]	182180[3]
98·2% (−8·4%)[4]	104·7% (+4·2%)[5]	101·5% (−8·1%)[6]
52 − 101 − 210[7]	11[8] −	A[9]

(1) Name of bull, (2) Breed of bull. (3) Herd-book number. (4) Average milk-yield production-ability index of the bull's daughters. (5) Average fat-content index. (6) Average fat-yield index. After each index figure the difference between the index for the daughters and the index of their dams is given in brackets. (7) The number of daughters (all daughters with first-lactation record taken into account) whose records were used for the progeny test, followed by the number of daughters produced by the bull, and by the number of its offspring irrespective of sex. (8) Age of bull at the time of the progeny test or at its disposal, in years and days. (9) Cause of disposal, e.g. TB = reactor to tuberculin test, A = old age, S = sterility, &c. When no entry is made in this column it indicates that the bull is still in active production, and its 'abstract' is not final.

The progeny-test 'abstract' of K.F. 3 shows that K.F. 3 with a milk-yield production-ability index of 98·2 per cent. was a medium-quality

Dairy Shorthorn bull. The negative value which is in brackets (−8·4 per cent.) indicates that for milk yield the bull was not good enough to effect an increase in milk production in the herd in which he was used. The

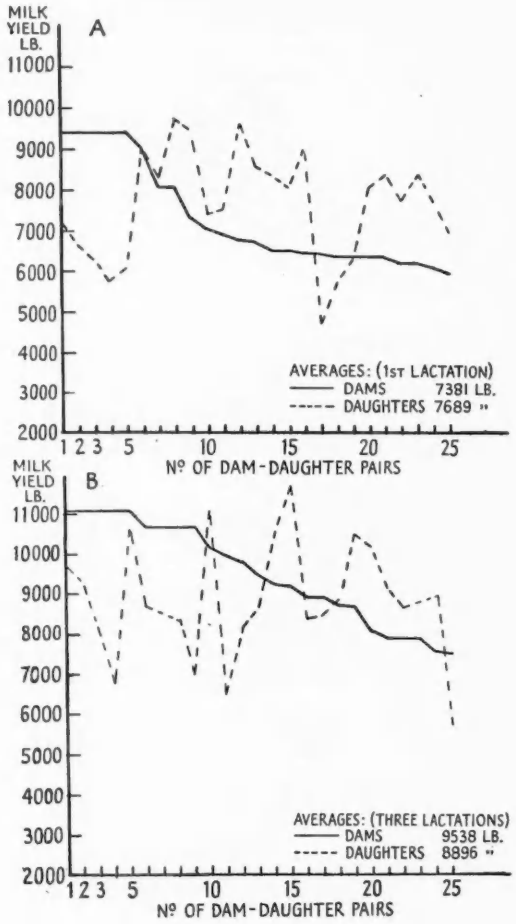

FIG. 7. First-lactation *v.* average-lactation records in progeny testing.

figures actually indicate that on the average K.F. 3 depressed the milk yield of his daughters as compared with that of the dams to which he was mated.

On the other hand, for fat-content, K.F. 3 was above average (index = 104·7 per cent., and he was able to improve the fat-content of his daughters. Evidently for the latter reason he was kept in the herd.

The fat-yield production-ability index (101·5 per cent.) confirms the mediocre value of the bull. One has, however, to remember that the breed standards which lie at the basis of the calculated indices were arbitrarily chosen and they are fairly high as compared with the country's average. In the prevailing conditions a bull attaining the standard must be considered a good-quality bull.

The abstract formula provides also the essential information on the number of daughters whose records contributed to the index figures. A person interested in the particular bull will, of course, be seeking information on the fate and reasons for disposal of the 49 heifers which in our case did not complete their first lactation, and the breeder should be prepared to supply detailed information on the subject (as given in Table 1).

Summary

1. Four methods of progeny testing of bulls based on dam–daughter comparison, the inheritance grid, the inheritance curves, the performance card, and a tabular method, are illustrated on data relating to one bull from the N.I.R.D. herd.

2. The various difficulties inherent in progeny testing are discussed.

3. A standard method for presenting results of a progeny test is suggested.

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AVAILABILITY OF NITROGEN IN COMPOSTS PREPARED FROM WASTE MATERIALS

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Introduction.—During the war years the author investigated in detail the preparation, nature, and use of composts prepared from straw and town refuse treated with sewage sludge; a summary of his work on town refuse and a more comprehensive account have appeared elsewhere [1, 2].[1] It was soon realized that in order to obtain the maximum results from the use of composts, some knowledge of their state of maturity and the availability of their nutrients was indispensable. Special attention was paid to the availability of nitrogen in composts. The methods used and the results obtained were described recently [3], but in view of delayed publication, a brief account of them is given in this place.

The decomposition of organic matter in the compost heap is largely a biological process. The materials used in the preparation of composts have normally a high initial carbon/nitrogen ratio, and one of the primary objects of composting is to lower this ratio to such a level that the contained nitrogen is quickly liberated in a form available to plants. Much research has been carried out to determine the relationship between carbon/nitrogen ratios and the availability of nitrogen in organic matter, but the results have often been conflicting owing to the variable nature of the material under investigation.

Determination of carbon/nitrogen ratio.—A difficulty arises when determining C/N ratios in town-refuse composts because they contain an appreciable amount of inert carbon in the form of coal and its degradation products. In the early stages of the work this caused much difficulty, but a method was evolved by the writer for separating and estimating this biologically inert material. The method is based on the removal of normal plant-constituents by chlorination and treatment with sodium sulphite, followed by the removal of cellulose with cold 72 per cent. sulphuric acid. Carbon and nitrogen are determined on the residue and these values are deducted from the total carbon and nitrogen. The corrected C/N ratios agree very well with the results of nitrification tests (Table 1); the ratio in the inert residue varies from 50 to 55, and this result, together with its dark colour, suggests that it may be a mixture of coal and elemental carbon. Composts having corrected C/N ratios less than 20:1 liberated nitrogen when added to soil; those with corrected ratios greater than 20:1 immobilized soil nitrogen.

The method, although useful for research purposes, is too lengthy for routine analysis and has been superseded by the fermentation test. It was found that the Walkley–Black [4] method for estimating organic

[1] This work was carried out at Reading University under a grant from the Agricultural Research Council.

TABLE 1. *Relationship between Carbon/Nitrogen Ratio, Nitrogen Availability, and Plant Growth*

Refuse–sewage sludge composts	*Total C/N ratio*	*Corrected C/N ratio*	*Pot experiment effect on dry wt. (gm. per pot)*	
			Lettuce	*Rye-grass*
Refuse only . . .	35	28	−4·6	−3·3
Immature compost . .	27	24	−4·8	−3·1
Compost 4 months old .	26	18	..	..
Compost 6 „ „ .	21	13	+4·0	+3·4

carbon in soil gave a rapid and approximate estimate of available carbon in refuse composts. Some comparative results are given in Table 2.

TABLE 2. *Total and 'Available' Carbon in some Refuse–sludge Composts (as percentage of dry matter)*

Sample	*Organic carbon (Walkley–Black)*	*'Available' carbon (Bould)*	*Total carbon by wet digestion*
Compost C . . .	12·9	10·7	22·3
„ D . . .	15·6	12·4	22·3
„ E . . .	15·4	14·2	26·3
„ H . . .	15·5	16·5	29·1

Nitrogen as percentage 'loss on ignition'.—Some authors have postulated a relationship between total nitrogen, expressed as a percentage of dry matter, and nitrogen availability. Waksman [5], and Hutchinson and Richards [6] give a figure of 2 per cent. below which organic matter will not usually liberate nitrogen when added to the soil. Owing to the higher and more variable ash-content of composts prepared from town refuse, the writer found that nitrogen expressed as a percentage of 'loss on ignition' gave a truer value. As a result of many nitrification tests it was found that refuse composts with a value greater than 3 per cent. would liberate available nitrogen. In fully mature refuse composts the value becomes stabilized around 3·5 per cent.

Estimation of Available Nitrogen

1. *Rate of nitrification—Pot method.*—This is the usual method of mixing a known weight of compost with soil, giving optimum conditions for nitrification, determining the ammoniacal and nitrate nitrogen liberated after 1 or 2 months, and expressing the increase over controls as a percentage of the total nitrogen added.

2. *Perfusion method.*—The mixture is placed in a perfusion apparatus, designed by Lees and Quastel [7, 8]. The technique is based upon the principle of intermittent perfusion of small amounts of a known volume of liquid through a column of soil containing active nitrifying organisms. The liquid is automatically aerated at regular and frequent intervals. Owing to the frequent perfusion of liquid the concentration of nitrate in the soil and the solution are approximately the same. It is unnecessary therefore to disturb the column of soil, and small samples (2 ml.) are

withdrawn at intervals from the main volume of perfusate for ammonia and nitrate determinations. As in method (1), the sum of the ammoniacal and nitrate nitrogen formed in excess of controls (after 3 to 4 weeks) is expressed as a percentage of the total nitrogen added.

3. *Fermentation method.*—This method, devised by the author, was based upon a suggestion by Christensen, quoted by Waksman [5], and further elaborated by Niklewski [9] and Waksman and Heukelekian [10]. It is based upon the amount of carbon dioxide produced by known amounts of compost in the presence and absence of excess cellulose (with and without known amounts of added nitrogen) under specified conditions. The method can be used qualitatively for determining state of maturity, or quantitatively for estimating available nitrogen.

4. *Pot experiments.*—The general technique employed is to grow plants in pots holding about 20 lb. of fresh soil. Fresh compost is added in amounts varying from 0·5 to 2 per cent. on a dry-weight basis. Several indicator plants are used, but spinach-beet is the most useful for nitrogen because leaves can be removed throughout the growing-season without harming the growth of the plant. Adequate amounts of potassium and phosphate are added before seed sowing. Two methods of estimating available nitrogen are employed:

(*a*) A pot series is included without compost to which increasing amounts of inorganic nitrogen are added in the presence of adequate basal phosphate and potash. Yields of dry matter from plants in this series are plotted on a curve so that increased yields of dry matter produced by addition of compost can be converted into terms of available nitrogen. Compost should be added at two or more rates.

(*b*) The plants are harvested, dried, weighed, and analysed for total nitrogen. The increased uptake of nitrogen by plants receiving compost over controls gives an estimate of the available nitrogen. In both these techniques loss by leaching should be prevented.

Results of availability tests.—Table 3 contains values for percentage of available nitrogen in straw–sludge and refuse–sludge composts as

TABLE 3. *Percentage of Available Nitrogen in Composts as estimated by Four Different Methods*

Compost	*Nitrification pot method*	*Nitrification perfusion*	*Fermentation*	*Pot expt. by analysis*	*Nitrogen H_2O-soluble*
SC 9	10·2	..	22·0	..	16·6
„ 15	7·6	..	17·4	..	9·5
„ 18	7·6	7·8	9·5	7·8	..
A 48	..	..	7·7	..	4·8
A 52	4·3	..	16·4	..	11·3
R 4	..	..	5·7	..	..
RC 15	..	..	5·1	5·6	6·3
RC 20	..	..	..	11·5	..
RC 26	4·4	..	5·7	..	..
RC 32	6·8	7·3	13·7	..	..
RC 35	7·9	9·5	14·3	..	..

A and SC = straw–sludge compost; RC = refuse–sludge compost; R = refuse only.

determined by the methods described above. Although the results obtained by different methods are not always concordant, they all indicate that the nitrogen in mature composts is not very readily available, a finding which is confirmed by field experiments. This is in contrast to the availability of nitrogen in such organic fertilizers as dried blood and meat-and-bone meal.

The fermentation method gives higher results than the other methods. This is to be expected on theoretical grounds because it gives an estimate of total availability, whereas the other methods indicate the amount of nitrogen available for plant-growth after the requirements of the ammonifying and nitrifying organisms have been satisfied. If allowance is made for this the fermentation method has certain advantages. The apparatus required is simple to construct and results can be obtained in about 14 days.

Field Experiments

Field experiments have confirmed the laboratory tests. In all cases greater yields have been obtained when inorganic nitrogen has been used in addition to composts. The results of one experiment with cabbage are given in Table 4.

TABLE 4. *Effects of Organic Manures, with and without Inorganic Nitrogen, on the Yield of Cabbage.* (*Total weight in lb. from* $\frac{1}{8}$ *acre.* $N = 1\frac{1}{2}$ *cwt. ammonium sulphate per acre*)

	Refuse compost	*Screened dust (refuse)*	*Cow-manure*	*Straw-sludge compost*	*Control*	*S.E. total of 5 plots*
Control . .	4,809	4,055	4,032	4,025	3,535	±145·4
Added N . .	5,143	4,725	4,760	4,742	4,228	..
Response to compost . .	+1,274	+520	+497	+490	..	..
Response to N .	+334	+670	+728	+717	+693	..

Refuse compost alone lowered the response to inorganic nitrogen by a significant amount, a result probably due to its fairly high content of ammoniacal nitrogen.

In a large-scale field experiment in progress at Long Ashton to test the effect of various organic manures on the growth, yield, nutrition, and vitamin-C content of black currants, the availability of nitrogen in compost and farmyard manure has been shown to be less than it is in sewage sludge and meat-and-bone meal, and to be inadequate for maintaining maximum growth and a suitable nitrogen status in the plant when applied on an equal organic-matter basis to 10 tons per acre of farmyard manure. The effect on growth and leaf-nitrogen is shown in Tables 5 and 6.

Nitrogen Changes During Decomposition

Refuse–sludge composts.—The values for available nitrogen given in Table 3 were obtained from mature composts. The low availability of

TABLE 5. *Effects of Organic Manures, applied on an Equal Organic-matter Basis, on the Growth and Leaf-nitrogen Content of Black Currant, var. Mendip Cross*

	Stable manure*	*Sewage sludge*	*Straw–sludge compost*	*Straw–nitro-chalk compost*	*Nitro-chalk 6 cwt. p.a.*	*Control*	*S.E. mean*
Pruning wts. in lb. mean wt. per bush	1·91	2·31	1·41	1·62	2·00	1·23	0·16
Total leaf-nitrogen as % of dry wt.	2·56	2·78	2·57	2·56	2·91	2·55	0·036

TABLE 6. *Effects of Organic Manures, applied on an Equal Organic-matter Basis, on the Growth and Leaf-nitrogen Content of Black Currant, var. Cotswold Cross*

	Stable manure*	*Sewage sludge*	*Town-refuse compost*	*Meat-and bone-meal 10 cwt. p.a.*	*Nitro-chalk 6 cwt. p.a.*	*Control*	*S.E. mean*
Pruning wts. in lb. mean wt. per bush . .	2·06	2·52	1·97	2·78	2·74	1·59	0·23
Total leaf-nitrogen as % of dry wt. . .	2·72	3·07	2·79	2·94	2·97	2·62	0·039

* Basic treatment 10 tons fresh weight per acre per annum (2nd year of treatment). All plots received basal K.

their nitrogen raises the question whether composting as generally practised is the best and most economical method of returning organic matter to the soil. The high temperatures developed during decomposition undoubtedly make the final product a safer and pleasanter material to handle, but the losses of organic matter and nitrogen can vary from 10 to 40 per cent., depending on the conditions and duration of the process.

The changes with age in the contents of total and ammoniacal nitrogen of refuse–sludge composts are shown in Table 7. After treating the refuse with liquid sewage sludge and aerating, rapid ammonification of the nitrogen compounds takes place, between a quarter and a third of the total nitrogen being present as ammonia after fourteen days. If the

TABLE 7. *Changes in the Total and Ammoniacal Nitrogen Contents of Refuse–sludge Composts with Age and Storage Conditions*

	Days from sludging	*Storage conditions*	*Total N*	*Ammon. N*	*Ammon. N as % of total N*	*Total N as % of loss on ignition*
			As % of dry wt.			
Refuse only .	..	..	1·181	0·118	10·0	2·95
Compost	14	Aerobic	1·483	0·405	27·3	3·37
,,	35	,,	1·305	0·179	13·7	3·01
,,	156	Anaerobic	1·283	0·090	7·0	3·55

material could be used at this stage, without desiccation and loss of ammonia, it would form a valuable supply of nitrogen. If, however, aerobic conditions are allowed to prevail in the compost heap, the high temperature and alkaline reaction result in heavy losses of ammonia. Some re-utilization of nitrogen takes place, but the secondary nitrogen compounds, or modified primary ones, appear to be very resistant to biological attack. Little more than the water-soluble fraction becomes available during the first growing-season.

Rothamsted field experiments have shown [11] that when straw and ammonium sulphate were added separately to a potato crop the yield was greater than when the same quantities were used after composting. A further important aspect to be considered is the effect of organic matter on soil structure. According to Geltzer, quoted by Russell [12], it is the active decomposition of organic matter within the soil that is responsible for improving soil structure. He uses this theory to explain the beneficial effect of grass on structure.

In the light of these results a preliminary pot experiment was carried out to compare composts prepared from straw and sewage sludge under controlled laboratory conditions with equivalent amounts of straw and sludge allowed to decompose in the soil prior to seed sowing.

Combined composting and pot experiment.—Quantities of chopped straw and dried sewage sludge were mixed in such proportions (1:2) that on theoretical grounds no nitrogen immobilization should occur when added to soil. Half the samples were treated with water and incubated for various periods under optimum conditions for decomposition. The other half were mixed with soil in pots for varying periods of time before seed-sowing. Six replicates were used for the compost work, four of which were used in the pot experiment and two for chemical analysis. Large glazed earthenware pots were used holding 20 lb. of moist soil. Each treatment was replicated four times, half the pots receiving basal phosphate and potash. Spinach-beet was the indicator plant. A series with inorganic nitrogen was set up at the same time.

The changes in the nitrogen fractions, and losses of organic matter and total nitrogen for the laboratory composts, are shown in Table 8. The results are in keeping with those of large-scale experiments. It will be noticed that with straw–sludge composts no great accumulation of ammoniacal nitrogen takes place as it does in refuse–sludge composts.

TABLE 8. *Changes in Nitrogen-content, and Losses of Organic Matter and Total Nitrogen during Decomposition of Straw–sludge Composts in the Laboratory*

Decomposition period, weeks	*Loss of organic matter* %	*Loss of N* %	*As % of dry wt.*		
			Total N	*Ammon. N*	*Nitrate N*
3	15·0	14·7	1·995	0·007	Nil
6	19·4	10·1	2·157	0·033	0·034
9	21·9	11·2	1·192	0·009	0·067

TABLE 9. *Effect of Straw–sludge Mixtures and Composts on the Growth of Spinach-beet, and the Recovery of Total Nitrogen*

	L.0 S.9	*L.3 S.6*	*L.6 S.3*	*L.9 S.0*	*L.6 S.0*	*L.3 S.0*	*L.0 S.0*	*Soil only*	*S.E. total of 4 pots*
Dry wt. in gm. from 4 pots . . .	21·32	15·13	17·56	22·12	18·07	15·60	15·20	9·60	1·405
Increase over controls % . . .	122	58	83	130	98	63	58	..	..
N recovered as % of original N . .	5·0	2·5	3·7	5·2	4·2	2·7	2·6	..	..
N recovered as % of N added . .	5·0	2·9	4·1	5·9	4·7	3·2	2·6	..	..

L = number of weeks' decomposition in the laboratory before adding to soil.
S = number of weeks in soil before seed sowing.

Treatments were significant at 1 per cent. level of *P* for dry matter. There was no significant response to addition of phosphate and potash. The response to compost and mixtures was therefore a nitrogen effect. The interesting result is that decomposition within the soil for nine weeks was as effective on yield and recovery of nitrogen as decomposition before addition to the soil. This is in keeping with the Rothamsted results with potatoes. The recovery of nitrogen was low and only slightly greater than the sum of the ammoniacal plus nitrate nitrogen in the compost.

It would be interesting to repeat the experiment with refuse–sludge composts, because the losses of nitrogen on storage are much greater than with straw–sludge composts. In stressing the nitrogen side of composting the author does not wish to give the impression that the nutritional value of composts is of paramount importance. In fact the experimental results show quite clearly that as far as nitrogen is concerned composts compare unfavourably with equivalent amounts of inorganic nitrogen. In countries where labour is dear it would be advisable to investigate more fully methods of returning organic matter to the soil, and not take for granted that because a compost looks and feels 'good' that it will give the highest yields and be most effective on soil structure.

Summary

1. Four methods of estimating available nitrogen are briefly described, and results are given for some representative refuse and straw composts.

2. Results of two field experiments are given indicating the effect of various organic manure and inorganic nitrogen on the growth, yield, and nitrogen status of two different crops.

3. Changes on storage in the nitrogen status of refuse–sludge composts are outlined.

4. Results of an experiment to test the effect, on the growth and recovery of nitrogen, of decomposition of straw–sludge mixtures outside and within the soil are described.

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EFFECTS OF GRAZING INTENSITY AND FERTILIZER TREATMENT ON TRANSVAAL HIGHVELD

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THE influence of different cutting and fertilizer treatments upon pasture productivity and root-reserves of grasses under Transvaal conditions has been described previously [1, 2, 3]. The present paper reports the results of a combined grazing and fertilizer experiment, conducted by the writer at Frankenwald, the Botanical Research Station of the Witwatersrand University, near Johannesburg.

Experimental

The area chosen for this experiment was relatively undisturbed natural veld, which previously had been exposed to uncontrolled light grazing. The dominant species of grasses were *Trachypogon plumosus* and *Tristachya hispida*. *Monocymbium ceresiiforme*, *Harpechloa falx*, *Elyonurus argenteus*, *Eragrostis chalcantha*, *Brachiaria serrata*, *Digitaria tricholaenoides*, *Microchloa caffra*, and others occurred less frequently. The soil of the area is an acid loamy sand on a subsoil of decomposed granite. The results of a representative soil analysis have already been given [1]. The annual rainfall during the four seasons of the experiment (1939 to 1943) ranged from 25·3 to 33·3 in., with an average of 31·1 in.

In January 1939 sixteen plots each of 225 sq. yd. were laid out, representing four different treatments in four replications, arranged in the form of a randomized-block experiment. Controls were provided by two strips 3 yds. wide running through the whole experimental area. The controls remained unfertilized and protected from grazing, but the old herbage was removed by cutting every year in mid-winter, except in 1939 when the whole area was subjected to a 'burn'.

The experiment thus consisted of the following treatments:

1. Control: protected and unfertilized (C).
2. Moderately grazed, fertilized (MG-F).
3. Moderately grazed, unfertilized (MG-UF).
4. Heavily grazed, fertilized (HG-F).
5. Heavily grazed, unfertilized (HG-UF).

The treatments were started in January 1939, and were continued for $3\frac{1}{2}$ seasons, i.e. until the winter of 1942.

The moderately grazed plots (Treatments 2 and 3) were usually grazed four times each season or once every 2 months between November and May. The heavily grazed plots (4 and 5) were grazed at monthly intervals, i.e. eight or nine times a season between September and May. For every grazing three or four head of cattle were placed in each plot so long as was necessary to achieve close grazing. The length of the individual grazing-periods hence varied with the season and according to the amount of herbage available, ranging, in general, from 3 to 8

hours. Except for the season 1940–1, when the fertilized plots (2 and 4) had to be grazed somewhat more intensively than the other plots on account of their higher productivity, the grazing pressure applied was the same for fertilized and unfertilized plots.

The number of grazing days per acre and season was 101 for the moderately grazed plots and 220 for the heavily grazed plots (averages for the $3\frac{1}{2}$ seasons 1939–42; calculated as outlined by Hall [4]). A comparison of these grazing data with those of Hall, Meredith, and Murray [5], who give the carrying capacity of an intensively fertilized camp of the same veld type as 116 pasture days per acre, shows that the treatment described here as 'moderate grazing' was in fact a rather intensive one.

In March 1939, 800 lb. of Kynoch Grass Mixture No. 1 were applied per morgen[1] in the plots of Treatments 2 and 4, corresponding to 40 lb. N, 120 lb. P_2O_5, and 40 lb. K_2O per morgen. During the following three seasons the same treatment was given in spring, followed by two dressings of 200 lb. (= 42 lb. N) of ammonium sulphate per morgen at convenient intervals during the growing season.

Results

Herbage data.—A series of herbage samples was taken from the plots between March 7, 1941, and Feb. 12, 1942. The moderately grazed plots were grazed four times during this period, the heavily grazed ones eight times. In three of the four plots of each treatment some 1 sq. m. quadrats were laid out. One of these quadrats was cut at every grazing immediately before the plot was grazed, a new quadrat being cut at every grazing. In the ungrazed control four quadrats were harvested in winter, namely, on Aug. 6, 1941. The individual herbage samples were air-dried, and ultimately the herbage collected from each plot was combined and weighed, a composite sample of each treatment being used for chemical analysis. The results are given in Table 1.

Herbage yields.—The dry-matter yield from the fertilized, moderately grazed plots was significantly higher than that produced by any other treatment, the lowest yield being obtained in the control (harvested in winter). There was a definite interaction between fertilizer and grazing treatments. Under conditions of moderate grazing the application of fertilizers resulted in a highly significant yield increase (3,548 lb. $\pm$432) but with heavy grazing the fertilizer effect, although positive, was statistically insignificant. Heavy grazing (as compared with moderate grazing) significantly reduced the herbage production where fertilizers had been applied (namely, by 2,200 lb. $\pm$708) but not in the unfertilized plots. It should be mentioned that these herbage-yield data are undoubtedly over-estimations, since the cuts yielded not only the herbage produced since the plots were last grazed, but also included all herbage left intact at the last grazing before the cutting date.

Chemical composition of herbage.—Fertilizer treatment produced under both heavy and moderate grazing a herbage of higher protein, phosphorus, and potash contents; the other constituents were, generally, little influenced by fertilizer treatment, except total ash, which was

[1] 1 morgen = 2·12 acres.

TABLE 1. *Herbage Data 1941–2*

Treatment	*MG-F*	*MG-UF*	*HG-F*	*HG-UF*	*Control*
Yields (lb. dry-matter per acre).					
Yield	8,021	4,473	5,821	4,611	3,540
Standard error	±380	±199	±596	±691	±294
Chemical composition (constituents as percentages of dry-matter).					
Crude protein	6·8	5·5	8·8	7·4	2·1
Ether extract	1·5	1·1	1·3	1·3	1·1
N-free extract	51·7	53·7	49·7	49·0	55·9
Crude fibre	34·0	32·1	31·2	29·3	35·3
Total ash	6·0	7·6	9·0	13·0	5·6
Phosphoric oxide	0·45	0·32	0·43	0·30	0·13
Potash	1·31	1·11	1·61	1·04	0·56
Lime	0·39	0·40	0·44	0·39	0·29
Nutrient-uptake (lb. per acre).					
Nitrogen	87·4	39·4	82·0	54·3	11·7
Phosphoric oxide	36·1	14·3	25·0	13·8	4·6
Potash	105·0	49·7	93·8	47·9	19·8
Lime	31·3	17·9	25·6	18·0	10·3

higher in the herbage from the unfertilized plots. The younger herbage from the more frequently grazed plots was higher in protein, total ash, and, where fertilizer had been applied, also higher in potash than that of the moderately grazed veld. The percentages of nitrogen-free extract and crude fibre were both lower under conditions of heavy grazing. The herbage from the control which was harvested in winter was very low in protein, phosphorus, potassium, and calcium; this confirms the results of previous workers, who pointed out the low nutritive value of such winter herbage [6].

Nutrient-uptake.—The nutrient yields (in lb. per acre) were highest in the fertilized, moderately grazed plots. The application of fertilizers caused a considerable increase in the nutrient-uptake under both grazing intensities. Though the herbage of the heavily grazed plots was superior in quality to those moderately grazed, the reduction of the dry-matter yields by heavy grazing resulted in decreased nutrient yields, at least where fertilizer had been applied.

Underground development and reserves of the entire sward.—In June 1942 one quadrat of 2 sq. m. was dug to a depth of 9 in. in every plot as well as in each block portion of the control strips (i.e. 20 quadrats in all). All roots and rhizomes from this volume of soil were quantitatively collected, separated from adhering soil and shoots, air-dried, weighed, and analysed for total available carbohydrates [7], nitrogen, phosphoric oxide, and potash.

Root-weights.—The average root-weights for the five treatments are shown in Table 2. It will be seen that all four grazing treatments significantly reduced the root-weight as compared with that of the protected control. The bulk of the roots was smallest in the heavily grazed plots, and differences between these root-weights and those from

TABLE 2. *Weight of Roots*

(In pounds combustible dry-matter per acre to a depth of 9 in.)

Treatment	*Control*	*MG-F*	*MG-UF*	*HG-F*	*HG-UF*
Root-weight . . .	2,690	1,930	1,625	694	661
Standard error* . .		±190		±22	

* Calculated by analysis of variance separately for the two main groups [8].

the moderately grazed plots are also significant, but the effect of fertilizers on the root-weight was only slight and statistically not significant.

Chemical composition of roots.—The results of the chemical analysis of the root-material (Table 3) show that total available carbohydrates in the protected control were significantly higher than in the grazed plots, and although differences between the two grazing intensities were not significant, the roots harvested from the heavily grazed plots were characterized by the lowest carbohydrate-content. The application of fertilizers did not appreciably affect the total available carbohydrate-content of the roots. All the grazing treatments, particularly heavy

TABLE 3. *Chemical Composition of the Roots*

(Constituents as percentages of the combustible dry-matter)

Treatment	*Control*	*MG-F*	*MG-UF*	*HG-F*	*HG-UF*	*Standard error* ±	*Sign. diff.* ($P = 0.05$)
Total avail. carbohydrate	6·79	5·14	5·03	3·77	4·33	0·46	1·42
Nitrogen .	0·44	0·60	0·51	0·74	0·59	0·03	0·09
Phosphoric oxide .	0·17	0·26	0·20	0·27	0·18	0·02	0·06
Potash .	0·36	0·42	0·35	0·37	0·38	0·03	0·09

grazing, increased the nitrogen-content of the roots, most probably owing to the relative increase in proteinaceous material brought about by the reduction in carbohydrates. The roots from the fertilized plots were significantly higher in nitrogen and phosphorus than those from the unfertilized plots. Differences in potash-content were in no case significant.

From Table 4 it will be seen that not only was the amount of total available carbohydrates in the roots from the protected control signifi-

TABLE 4. *Amounts of Total Available Carbohydrates in the Roots*

(In pounds per acre to a depth of 9 in.)

Treatment	*Control*	*MG-F*	*MG-UF*	*HG-F*	*HG-UF*
Total available carbohydrate . . .	181·4	98·9	82·0	25·2	28·6
Standard error* .		±15·5		±4·8	

* Calculated by analysis of variance separately for the two main groups [8].

cantly higher than under any other treatment, but heavy grazing resulted in a further very pronounced reduction as compared with moderate grazing. The roots of the moderately grazed plants contained approximately half as much total available carbohydrate as those from the protected veld, whereas heavy grazing reduced the amount to about 15 per cent. of that of the control.

Underground reserves of individual grass species.—Roots of seven of the most important species of grasses were separately sampled in the winter of 1942. From 40 to 100 tufts of each species were dug out to a depth of 3 to 4 in., and the roots were dried, weighed, and analysed for total available carbohydrates. Root-weights and amounts of total available carbohydrates were calculated per 100 tufts (Table 5).

With few exceptions, the root-weights were highest either in the protected control or in the moderately grazed plots, and lowest where the grass had been grazed heavily. Only in some of the species did the percentage of total available carbohydrates show a clear-cut relation to the grazing treatments. It was definitely lowered by grazing in *Brachiaria serrata*, *Microchloa caffra*, and *Tristachya hispida*. In other species, however, differences were small, and in the roots of some grasses even high values were encountered after heavy grazing. Such 'abnormal' responses have previously been recorded by the writer in certain clipping experiments [3]. The actual amounts of total available carbohydrates in the roots were, however, in all species distinctly reduced by grazing. The individual species obviously responded differently to the various treatments. *Elyonurus argenteus* and *Trachypogon plumosus* possessed the highest amount of total available carbohydrates when moderately grazed and fertilized, but the average amount was highest under protection and lowest in the heavily grazed plants. The method of calculating root-weights and amounts of total available carbohydrates per 100 tufts would not include any effects of the treatments upon the frequency of the species tested.

Recovery-growth and botanical changes.—In each plot (including the four block portions of the control strips) a 2 sq. m. quadrat was pegged out in the winter of 1942, and all old growth was removed from them. The plots remained protected during the following season and no fertilizer was applied. In Feb. 1943 the herbage was harvested for determining recovery-growth. Table 6 gives the yields of total herbage. The standard errors for total herbage and grass yields were calculated by analysis of variance, but those for the weeds are given separately for each treatment on account of their large variations [8].

The yields of both total herbage and grasses were significantly higher in the plots which had been moderately grazed and fertilized than those from the other four treatments (including the control). The heavily grazed, unfertilized plots gave the lowest yields, significantly lower than those of the control. The recovery-growth of grasses was significantly reduced below the level of the control by heavy grazing (with or without the use of fertilizers) and by moderate grazing without fertilizer applications.

TABLE 5. *Root-weights and Carbohydrate Reserves of Individual Grass Species*

Treatment	*MG-F*	*MG-UF*	*HG-F*	*HG-UF*	*Control*
Root-weight in grams of combustible dry-matter per 100 tufts					
Brachiaria serrata	88	84	64	51	152
Elyonurus argenteus	298	205	213	158	160
Eragrostis chalcantha	32	16	20	19	38
Microchloa caffra	183	168	125	150	173
Monocymbium ceresiiforme	30	38	18	12	173
Trachypogon plumosus	298	228	93	75	255
Tristachya hispida	405	318	228	188	590
Average	191	151	109	93	220
Total available carbohydrate per cent.					
Brachiaria serrata	4·13	4·51	2·67	2·68	7·06
Elyonurus argenteus	9·48	8·98	10·31	10·00	9·62
Eragrostis chalcantha	2·15	3·75	2·89	3·40	3·74
Microchloa caffra	2·50	2·12	1·75	1·80	2·77
Monocymbium ceresiiforme	5·48	4·78	4·01	10·57	5·54
Trachypogon plumosus	5·50	5·19	5·13	4·09	4·95
Tristachya hispida	8·34	8·68	9·10	8·81	11·29
Average	5·37	5·43	5·12	5·91	6·42
Total available carbohydrate in grams per 100 tufts					
Brachiaria serrata	3·6	3·8	1·7	1·4	10·7
Elyonurus argenteus	28·2	18·4	21·9	15·8	15·4
Eragrostis chalcantha	0·7	0·6	0·6	0·7	1·4
Microchloa caffra	4·6	3·6	2·2	2·7	4·8
Monocymbium ceresiiforme	1·7	1·8	0·7	1·3	9·6
Trachypogon plumosus	16·4	11·8	4·8	3·1	12·6
Tristachya hispida	33·8	27·6	20·7	16·6	66·5
Average	12·7	9·7	7·5	6·0	17·3

TABLE 6. *Recovery-growth, 1942–3*

Treatment	*Pounds dry-matter per acre*			*Percentage weeds*
	Total herbage	*Grasses*	*Weeds*	
Control	1,930	1,690	240 ± 45	12·0 ± 1·3
MG-F	2,460	1,930	530 ± 106	21·4 ± 2·8
MG-UF	1,640	1,300	340 ± 92	20·1 ± 5·0
HG-F	1,830	1,200	630 ± 162	34·7 ± 7·9
HG-UF	1,490	1,140	350 ± 31	23·9 ± 5·3
Standard error	±114	±66	..	..
Significant difference (P = 0·05)	351	203	..	..

Fertilizer treatment significantly increased the growth of weeds above that in the control areas under both grazing intensities. In all four grazing treatments the proportion of weeds (as percentage of the total herbage yield) exceeded that of the control, and, except for the MG-UF treatment, the differences are significant. The amount and proportion of weeds was, however, highest in the heavily grazed, fertilized plots. The dominant species of weeds were: *Conyza ambigua*, *Erigeron canadense*, *Gnaphalium undulatum*, *Haplocarpa scaposa*, *Helichrysum aureonitens*, *Helichrysum callicomum*, *Nidorella polycephala*, *Senecio laevigatus*, *Ursinia annua*, and *Verbena bonariensis*.

The recovery-growth of the ten most abundant species of grasses was determined separately, and it will be sufficient to indicate merely the more striking botanical changes. Of the species tested *Trachypogon plumosus*, *Tristachya hispida*, and *Monocymbium ceresiiforme* were reduced in quantity and percentage by the grazing treatments, particularly by heavy grazing. *Elyonurus argenteus* and *Eragrostis chalcantha*, on the other hand, yielded a greater bulk of herbage under grazing than under protection. *Digitaria tricholaenoides* was most abundant in the moderately grazed plots, and *Cynodon dactylon* where heavy grazing had taken place. Various secondary species of grasses, such as *Aristida* and *Eragrostis* spp. and others, were particularly frequent in the heavily grazed plots. Finally, it may be mentioned that heavy grazing resulted in the formation of bare patches and in a decrease of total vegetative cover.

Summary and Discussion

Results of this grazing experiment confirm previous cutting experiments carried out by the writer [1, 2, 3]. Like frequent cutting, heavy grazing lowered herbage yields and depleted underground reserves of grasses. Also, heavy grazing diminished the beneficial effect of fertilizers upon growth, and maximum nutrient yields were recovered from moderately grazed, fertilized veld. Fertilizer applications did not prevent the adverse effects of frequent defoliation or heavy grazing upon the development and the carbohydrate reserves of the underground parts but merely increased their contents of nitrogen and phosphorus.

Even moderate grazing as compared with protection resulted in a certain reduction in root-reserves. The ill effects of over-stocking and over-grazing are well known, but it would appear that in most species of grasses any degree of herbage utilization by cutting or grazing will unavoidably result in some reduction in stored underground reserves. This knowledge is of practical importance, since it emphasizes the need of judicious pasture management. Periods of intensive grazing should alternate with sufficiently long rest-periods to allow the vegetation to regenerate and to accumulate reserves. This can be achieved by suitable systems of deferred and rotational grazing adapted to the particular conditions of soil, climate, and vegetation prevailing in different regions.

In contrast to uniform close cutting, grazing resulted in pronounced changes in the botanical composition of the sward, such as have been reported also by other workers [9, 10, 11]. Such changes are largely due to the selective action of the grazing animal by which the more desirable

species are affected to a higher degree than less palatable ones. To a certain extent, the response of individual species depends on their growth habit. Prostrate species of grasses are, generally, more protected from grazing than upright ones; they consequently tend to thrive under conditions of intensive and even heavy grazing, particularly if like *Digitaria tricholaenoides* and *Cynodon dactylon* they are endowed with rhizomes possessing large stores of organic food reserves. That the growth of weeds was most pronounced in the fertilized, heavily grazed plots is understandable. Under conditions of heavy grazing the desirable species of grasses will, on account of the depletion of reserves, not be able to utilize the additional nutrients which thus become available to competing weedy plants.

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BREEDING FOR MILK IN A MEDITERRANEAN ENVIRONMENT

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WITH PLATE 4

THE introduction of European breeds of dairy cattle into tropical and sub-tropical areas has been widely attempted in the past with varying degrees of success. The eastern Mediterranean area, though outside the tropics, has a sub-tropical climate characterized by a low winter rainfall and a hot, dry summer with maximum temperatures of over 100° F.

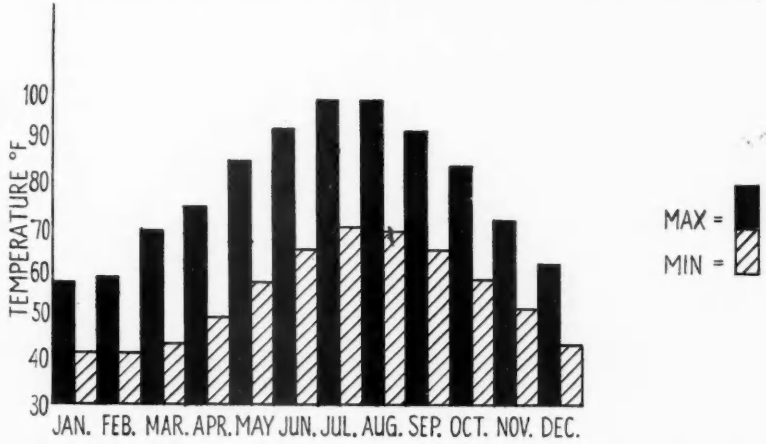

FIG. 1. Mean monthly maximum and minimum temperatures in °F. at Nicosia, Cyprus (20 yrs.' av.).

The climate of Cyprus is considered to be fairly representative of the Mediterranean type [1]. The mean maximum and minimum temperatures and monthly rainfall, given in Figs. 1 and 2, show that though the winter weather can be fairly cold, and in fact there is some frost in the plains, the summer temperatures are high, the extreme maximum temperature of 111° F. having been twice recorded in the last 20 years. Unlike the wet tropics, however, the humidity is low. The range of atmospheric temperature and of humidity outside which European cattle will not thrive are referred to by Wright [2], who states that the accepted upper limit which these cattle can tolerate is a mean annual temperature of between 65° and 70° F. High humidity (over 70 per cent.) combined with high temperature is an additional limiting factor.

In Fig. 3 the mean monthly temperature at Nicosia is contrasted with those for London and Colombo, representing temperate and wet tropical zones. Although Nicosia rises above Wright's critical zone of 65–70° F. for 6 months of the year, the humidity for the same period varies from 51 to 63 per cent., whereas in the wet tropics it seldom falls below 60 per cent. and in Ceylon is generally above 70 per cent. (Fig. 4). Thus, although summer temperatures are high in the Mediterranean climate they are not accompanied by high humidity, and there is a wide annual variation in temperature similar to the range in temperate zones. This range in temperature and, in particular, the fact that the humidity

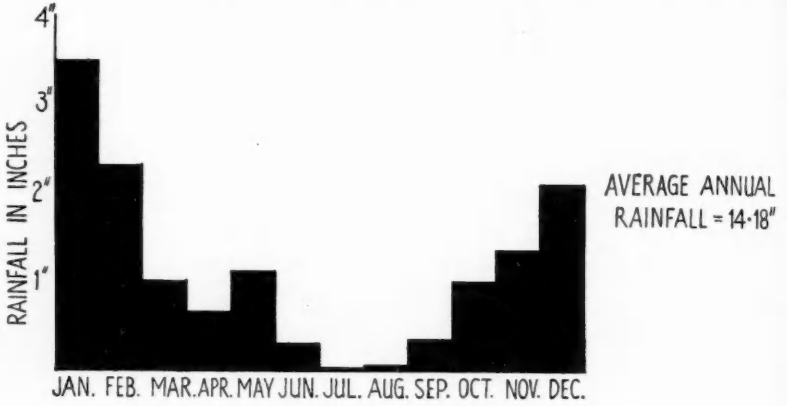

FIG. 2. Monthly rainfall at Nicosia, Cyprus (20 yrs.' av.).

is, by comparison with the wet tropics, comparatively low, may be considered to have an important bearing on the acclimatization of European breeds of cattle.

In the neighbouring countries (Turkey, Syria, Palestine, Egypt) the indigenous cattle are generally poor milkers, though there are some specialized dairy types such as the Lebanese breed; they are, however, mainly used as draught cattle. The native cattle in Cyprus are also never milked but are used for draught and, to a lesser extent, for beef. The introduction of dairy breeds to the eastern Mediterranean countries has taken place in order to obtain an economic milk-supply, usually for a special section of the population.

There is some evidence that European breeds (*Bos taurus*) when kept pure have not been entirely successful in the Mediterranean climate [3, 4]. There are few recent data available on the work done in Palestine and Egypt, but in both countries European breeds have been kept pure and have also been used for grading-up the native, 'baladi', cows. Provided disease-control and management are efficient, satisfactory yields of milk from pure-bred cattle have been obtained, but one of the main causes of European stock being unsuitable in Palestine and Egypt is the presence of tick-borne diseases (e.g. Piroplasmosis). In Cyprus, how-

ever, tick-borne diseases of cattle do not occur and dipping is unnecessary. Thus one of the major difficulties with which European cattle have to contend elsewhere in the Mediterranean is, fortunately, absent.

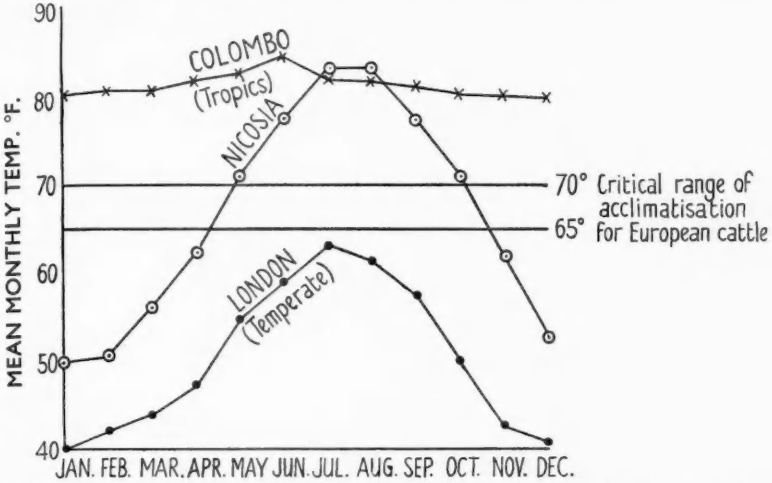

FIG. 3. Mean monthly temperatures at Nicosia, Cyprus, compared with temperate and tropical zones.

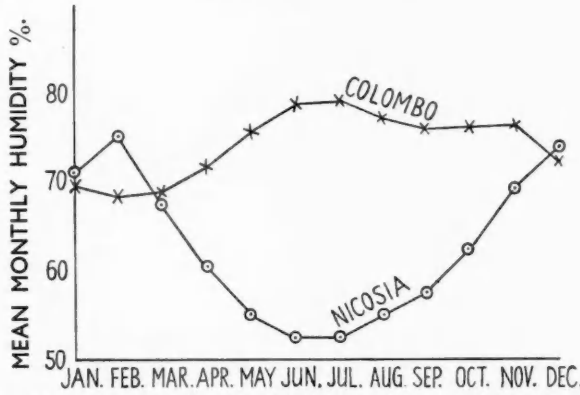

FIG. 4. Mean monthly relative humidity (per cent.) at Nicosia, Cyprus, and Colombo, Ceylon.

In Palestine the Jewish community has built up a thriving industry with the Dutch Friesian breed [4], and the Palestine Government has introduced the Kerry breed for improving the Arab cattle [5]. Although the pure-bred Friesians can become acclimatized, there appears to be a deterioration in subsequent generations [3] and cross-breeding with native breeds is therefore preferred. The Report of the Palestine Cattle

Breeders' Association (Milk Inspection Section) for 1934–5 [6] gives details of milk yields of Friesian and grade cattle; average yields of 9,300 lb. for pure-bred Friesians, 8,820 lb. for the first cross with the local (Damascus) breed, and 6,591 lb. for the Damascus, were recorded. In 1941 the average yield of cows in Jewish settlements and farms was given as 8,228 lb. [4]. In Egypt Khishin [7] states that Dairy Shorthorns and Jerseys have proved successful and yields of from 600 to 900 gal. have been recorded for Jersey cows. The Dairy Shorthorns have also been crossed with the local cattle to give a useful cross-bred cow. These recorded yields refer only to selected farms and to small numbers of animals kept under good conditions. There is, as yet, no evidence to justify a claim that European cattle are suitable for a wide range of conditions in the eastern Mediterranean.

In this paper an account is given of the introduction and breeding of European dairy cattle in Cyprus. This is, however, mainly confined to the work carried out at the Government Stock Farm at Athalassa.

Historical survey.—Importations of bulls of European breeds since the British occupation of Cyprus date back to 1896 or possibly earlier [8], but these bulls seldom survived long and have left no trace in the local cattle. In 1907, 2 Devon bulls (referred to at that time as North Devon) and 1 Galloway bull were imported, but only one of these (a Devon) survived and left a small number of half-bred progeny.

It was not until 1912 that serious consideration was given to proposals to import a breed with milking qualities and the South Devon was chosen. In that year 3 South Devon bulls and 6 cows were imported and a small herd was started at the Government Stock Farm, Athalassa, which was added to by the purchase of a few half-bred Devon heifers sired by the 1907 bull.

The Dairy Shorthorn breed was introduced in 1920, 29 head being imported in 1920–1, but bulls of both breeds as well as cross-breds were used in different parts of the island up to 1928.

Further changes in the breed were again made in 1928–9. Friesians were already being used in Jewish settlements with success and it was thought that a trial was justified in Cyprus; 1 Friesian bull was therefore imported in 1928 and was crossed with some of the existing female stock of Dairy Shorthorns and South Devons. In 1929, 2 Ayrshire bulls were obtained, and though only 1 survived for a few years traces of Ayrshire blood are still found in some herds. The Friesian bull was kept until 1935 (8½ years) and sired a number of calves. Seven of his sons, out of Shorthorn cows, were also used, the last of them being sold in 1939.

By 1934 there were no pure-bred Shorthorn bulls available although the bulk of the cows in the island had Shorthorn blood. It was, however, decided to continue with this breed and not switch over to Friesians; as a result, a Dairy Shorthorn bull was imported in 1935, and further importations followed in 1936 and 1938. The average age of 10 Shorthorn bulls used between 1935 and 1945 was 6·1 years, and 2 imported bulls were kept until they were 7 and 9¼ years old, respectively. In 1931 the Kerry breed was introduced by importing 1 bull and 4 cows from Eire. There was no intention of this breed competing with the large

breeds in the main dairying areas. The introduction was made for a special purpose—the encouragement of a dairy type of cow in the hill areas, partly as an alternative to goats. This policy did not, however, achieve great success, mainly due to the restricted nature of the experiment and because there was no demand for a milch cow in the hill areas at that time. There is now only a handful of Kerry cattle and their crosses in Cyprus.

The various importations of cattle are set out in Table 1.

TABLE 1. *Importation of Cattle 1907–46*

Year	*Breed*	*Numbers and sex*	
1907	North Devon	2 bulls	..
	Galloway	1 bull	..
1912	South Devon	3 bulls	6 cows
1920	South Devon	1 bull	3 cows
	Dairy Shorthorn	1 bull	3 cows
1921	Dairy Shorthorn	1 bull	24 heifers
1928	Friesian	1 bull	..
1929	Ayrshire	2 bulls	..
1931	Kerry	1 bull	4 heifers
1935	Dairy Shorthorn	1 bull	..
1936	Dairy Shorthorn	1 bull	4 heifers
1938	Dairy Shorthorn	..	3 heifers

Development of the Dairy Cattle Industry

Although imports of dairy cattle date from 1912, it was not until 1928 that any appreciable progress had been made. By that time there were about 50 dairy cows owned by local dairymen, and since then the numbers have gradually increased [9]. In 1945 there were just under 1,100 dairy cattle of all ages including 600 dairy cows, and by 1947 the number was estimated to be 1,200. This is approximately 3·5 per cent. of the total cattle population.

Sheep and goats form the bulk of the milk-producing animals in Cyprus as they do in neighbouring countries (Palestine, Syria, and Turkey). The total production of sheep's and goat's milk was estimated by Maule [9] to be 4 million gals. per annum whereas the total yearly output of cow's milk probably does not exceed 40,000 gal. or 1 per cent. of that of sheep and goats. It is obvious, therefore, that there is not likely to be (and, in fact, there has not been) any competition between sheep and cows in the milk market. Dairy cattle have been bred to supply the specialized market for bottled milk, whereas sheep's milk is largely used in the making of cheese, yaourt, and other milk products. Moreover, there has never been any attempt to grade-up the indigenous cattle for milk, nor has there been very much cross-breeding between native cows and Dairy Shorthorn bulls. Occasionally cross-bred cows are seen in local dairies, but it is not common and the amount of native blood in the dairy cattle in the island to-day is probably around 5 per cent.

The Department of Agriculture has played a major role in the development of the dairy cattle industry, for by the import of dairy cattle

from 1912 to 1921 it laid the foundation of the present industry. The Government Stock Farm at Athalassa has been the centre of the Department's breeding work. The dairy herd was founded in 1912 with the imported South Devon cattle and all stock imported since have been added to the herd. As it increased in size it became possible to sell surplus female stock. Bulls were stationed in the various towns where dairies were established and were available for stud purposes. Gradually the number of dairies grew and though most dairymen still own only a few cows, there are now several larger dairy farms and a few of these own their own bulls. Generally, however, dairymen relied on the Department to supply good bulls for breeding, and one of the Stock Farm's main functions was, therefore, the breeding of dairy bulls for use in different parts of the island. A nominal service fee of 1*s.* was charged and this rate has never been altered.

In the early years only some 3–4 bulls were required, but as the industry grew this number increased and the use of the bulls increased, as is shown in Table 2, which has been compiled from the Department's annual reports.

TABLE 2. *Dairy Shorthorn Bulls at Stud*

Year	*Number of bulls*	*Average number of services per bull*
1936	6*	50
1940	9	56
1946	14	68

* Including 5 cross-bred bulls.

The interest taken by local dairymen in the proper methods of milk production and management of their cattle has varied considerably and progress has undoubtedly been slow. Milk-recording has never been practised except by a very few individuals and then usually only as a result of the repeated advice of the Agricultural Department's staff. Figures for the average yield of milk per cow are, therefore, not available. Nevertheless, there is an increasing demand for cow's milk and, with greater experience, and as more building materials and equipment become available, it seems probable that methods of production and management will improve and that total output will continue to increase.

Breeding policy.—It has already been shown that up till 1934 government policy fluctuated and several breeds were imported. Though the milk was measured no accurate recording and comparison of the different crosses and breeds was made. Since that year accurate milk-recording and herd-records have been kept and a definite breeding policy has been adhered to [8, 11, 12].

The normal lactation records of all the Devon and Shorthorn cows in the herd for the period 1920–34, which are summarized in Table 3, showed that the latter breed was the better of the two [8, 10]. The average mature yields were calculated by Sanders's method [13], i.e. by

adding 30 per cent. to first lactation yields, 20 per cent. to second, and 10 per cent. to third lactations, all of 315 days.

TABLE 3. *Yields of Various Breeds obtained at Government Stock Farm 1920–34*

Breed or cross	*Number of lactations*	*Actual mean yield, lb.*	*Average mature yield, lb.*
South Devon and Grade Devon	68	3,966	4,335
Dairy Shorthorn . . .	95	5,091	5,680
Herd average	182	4,636	5,187

Furthermore, a comparison of the milk yields of the imported and home-bred Dairy Shorthorns up to 1934 showed that the home-bred cows gave an average of nearly 1,000 lb. more than the imported cows, as follows:

TABLE 4. *Yields of Dairy Shorthorn Cows 1920–34*

Number of cows	*Number of lactations*	*Average mature yield, lb.*
18 imported .	52	5,166
15 home-bred .	43	6,127
33 cows . .	95	5,680

It was concluded, therefore, that the Shorthorns bred in Cyprus were readily acclimatized and that no obvious degeneration had occurred.

Figures for the Friesian crosses at this time (1934) were insufficient to make a comparison possible [10], there being only 4 such cross-bred cows in the herd. It was, however, clear that by far the greatest proportion of blood in the existing dairy cattle was Dairy Shorthorn; the other breeds imported (South Devon, Friesian, and Ayrshire) had far less influence owing to the smaller numbers imported. Thus the decision was taken to concentrate on the Dairy Shorthorn breed as the main breed for all but the hill areas, where it was intended to use the Kerry breed. As a result of this policy further importations of Dairy Shorthorns were made between 1936 and the outbreak of war in 1939, 1 bull, 'Chalfield Minstrel 2nd', and 4 heifers being imported in 1936 and 3 heifers from the Lockinge herd in 1938.

The herd records obtained since 1934 relate, therefore, to the 15 Dairy Shorthorn and cross-bred cows and heifers in the herd on December 31, 1934, to the 7 imported pedigree Dairy Shorthorn cows, and to the progeny of all these.

Management.—The feeding and management of the dairy herd at Athalassa was reorganized in 1934–5 and greater accuracy both in feeding, in dairy routine, and in calf-feeding was introduced.

Feeding has been based on growing the maximum amount of forage possible, including hay and silage, both of which are grown only on a very limited scale in the island, and on the purchase of oil-cakes, bran,

carobs, and grain, as required. Grazing is confined almost entirely to the natural flush of grass, which appears about December and lasts until March–April. During the other months green food must be grown for the herd; it consists mainly of lucerne, maize, and berseem. Lucerne is available during the spring and summer to supplement the indigenous grass, the cows being lightly grazed over the paddocks on the farm.

Maintenance requirements have usually been met by grazing or by feeding green fodder. This has been supplemented or replaced when necessary by hay or silage, usually made from cereal-legume mixtures, and by straw. Small quantities of lucerne hay were reserved for special cows.

The production ration consisted of a mixture of barley or oats, bran, vetches, cottonseed cake, sesame or linseed cake, and locust beans (carobs) in proportions depending on availability and price but calculated to supply the desired amount of starch and protein equivalents. This ration was fed according to milk yield, allowing a little extra in the first month or two after calving to encourage increased production. Calves were always weaned at 3–7 days old and pail-fed on accurate quantities of whole milk until they were 6–7 months old. Hay or straw, grain, and plenty of green food were fed to them, the amounts of the former depending on the available grazing. The cattle were kept out of doors each day as long as temperatures and weather conditions permitted. Thus, in winter they might be out all day and night, and in summer they would be housed during the middle of the day or kept in a shady paddock, and be out all night. Care was taken to allow a proper dry period between lactations, and so far as possible calvings were arranged to occur during the cooler months of the year. Bulls were never allowed to run with the herd but were kept tied up and exercised daily.

Age at first calving.—Normal practice since 1934 has been to calve down heifers in winter and spring, and heifers were, therefore, served so that, as far as possible, this was achieved. The average age at calving of 32 heifers bred at the Stock Farm between 1933 and 1944 was 2 years 205 days, or just under 31 months. The figure varied from a minimum of 22 months to a maximum of 41 months. Growth and development were considered normal and the age at service compares well with the normal practice in Britain.

Lactation milk yields.—The average full-time lactations for the herd from 1920 to 1934 are summarized in Table 3, the average of 182 lactations being 4,636 lb. in 280 days. The annual average yield varied during this period from 3,523 lb. (1922) to 6,212 lb. (1933). Table 5 gives the average full-time lactation yield from 1935 to 1946.

Tables 3 and 5 show that the herd gave a considerably higher average yield from 1936 onwards than in the years 1920–34. The jump in the herd average in 1936 coincides with a change in management in 1934–5, and it is probably reasonable to assume that the effect of feeding balanced rations and of more careful management combined with more accurate recording was responsible for the increased average yields after 1935.

TABLE 5. *Average Lactation Yields 1935–46*

Year	*No. full-time lactations*	*Mean lactation yield, lb.*	*Mean lactation period, days*	*Average daily yield, lb.*	*Average butter-fat, per cent.*
1935	7	5,637	257	21·9	4·06
1936	11	8,158	308	26·5	3·88
1937	8	8,454	310	27·3	3·60
1938	12	8,859	335	23·5	3·68
1939	13	8,522	303	28·0	3·80
1940	13	9,424	307	30·7	3·57
1941	13	9,289	334	27·8	3·64
1942	11	8,912	357	25·0	3·59
1943	8	9,208	295	31·2	3·43
1944	14	8,474	318	26·6	3·25*
1945	11	8,465	306	27·8	3·05*
1946	12	9,544	319	30·0	3·63
Av. of 12 years	133	8,579	312	27·5	

* *Note.* Tests done on morning samples only during part of 1944 and throughout 1945.

Improvement in the average daily yield per cow in milk also occurred over the 26 years, as the following figures show:

Period	*Average daily yield per cow, lb.*
1921–5	14·7
1931–5	20·8
1941–5	27·7

Up to 1936 no yields of over 10,000 lb. had been recorded but in that year 2 cows completed lactation yields of over 11,000 lb., the best being 11,618 lb. in 297 days by a cross-bred Friesian–Shorthorn cow in her third lactation. Since that year 41 lactations of over 10,000 lb. have been recorded. In Table 6 the distribution of cows according to their lactation yields is shown.

TABLE 6. *Distribution of Lactation Yields*

Milk yield, lb.	*No. of cows*	*Per cent. of total*
Under 6,000 . . .	24	18·0
6,000–8,000 . . .	33	24·8
8,000–10,000 . .	35	26·3
10,000–12,000 . .	24	18·1
Over 12,000 . . .	17	12·8
Total	133	100·0

It will be noticed that only 18 per cent. of the lactations were below 6,000 lb. and nearly 31 per cent. were above 10,000 lb. These figures compare favourably with those obtained in Palestine for Friesian crosses in Jewish settlements [6]. The comparative percentage figures were

23 per cent. under 6,600 lb., 48·5 from 6,600 to 9,900 lb., and 28·5 over 9,900 lb. There has not, however, as in Palestine, been any loss of constitution or stamina either in imported cows or in cows bred in the island. The figures of the herd average yields confirm this and, furthermore, since 1935 the home-bred Dairy Shorthorns have given yields almost as high as those given by the cows imported in 1936–8. These yields are given below (Table 7) and are corrected to 'average mature yields' for all cows. The home-bred cows include $\frac{3}{4}$-bred Dairy Shorthorns.

TABLE 7. *Comparative Yields of Dairy Shorthorn Cows 1935–46*

No. of cows	*No. of lactations*	*Average mature yield, lb.*
7 imported . . .	28	9,763
17 home-bred. . .	49	9,353
24 cows . . .	77	9,502

The yield of 17 home-bred cows is only 400 lb. lower than that of the 7 imported cows. This difference, compared with the opposite effect obtained in 1920–34 (Table 4) probably reflects the greater care taken in selection of the cows purchased in England, rather than any deterioration in their progeny. The average yields for both groups are high and the home-bred cows have compared favourably with the imported cows in regularity of breeding.

Outstanding performances (cf. Plate 4).—The records of 7 outstanding cows are set out in Table 8. These show the total lifetime lactation yield and percentage of butter-fat as well as each cow's own best performance. Of these 7 cows, 2 are daughters of 1 cross-bred Ayrshire cow (No. 335), which had an important influence on the herd. The individual lactations given are not the 7 best ever recorded, but that of no. 321 is the highest yield obtained at the Stock Farm and probably in Cyprus. This cow gave over 60 tons of milk in her lifetime and was eventually destroyed on account of debility when she was 16 years old.

TABLE 8. *Records of Seven Outstanding Cows*

No. of cow	*Breeding*	*No. of lactations*	*Total lifetime yield of milk, lb.*	*Av. butter-fat, per cent.*	*Best performance*			
					Milk yield	*Days in milk*	*Butter-fat, per cent.*	*Wt. of fat, lb.*
321	Friesian × Dairy Shorthorn .	13	133,102	3·28	15,124½	336	3·12	474
343	Imported Dairy Shorthorn .	8	77,206	3·2	14,924½	359	2·90	429
352	Imported Dairy Shorthorn .	7	71,300*	3·43	12,066	296	3·56	430
335	Ayrshire × Dairy Shorthorn .	6	58,296	3·9	11,591	334	3·98	461
347	Home-bred Dairy Shorthorn .	6	52,487*	3·83	13,975	338	3·98	556
348	¾ Dairy Shorthorn ¼ Ayrshire . .	6	58,371*	3·53	12,471½	318	3·56	430
361	¾ Dairy Shorthorn ¼ Ayrshire . .	3	33,977*	3·75	11,866	296	3·65	413

* *Note.* Cow was still alive in 1947.

Butter-fat content of milk.—Tests of the milk of individual cows for butter-fat percentage have been made monthly or occasionally in alternate months since 1935. These tests were originally made by sampling the milk on 3 successive days, one test being made for each mixed sample, but in 1944 and 1946 tests were done on morning's and evening's milk separately. During part of 1944 and in 1945 only morning's milk was tested and the figures for 1945 are therefore not included in this summary. Since 1945 tests have been done twice monthly. Between 1935 and 1946 the average annual butter-fat content of the milk of the herd varied from 3·43 (1943) to 4·06 (1935) with an average for 102 lactations of 3·63 per cent. Table 5 gives the annual average for these years, calculated from the tests on individual samples. The 102 separate lactations are classified in Table 9. This shows that the figures for nearly 50 per cent. of the cows fell between 3·51 and 4 per cent.

TABLE 9. *Butter-fat Content of Milk (102 lactations)*

Butter-fat, per cent.	*Percent. of cows within group*
Under 3	4·0
3·0–3·5	31·3
3·51–4·0	49·0
Over 4·0	15·7
Total	100

Influence of different bulls on milk yield.—Prior to 1934 one Dairy Shorthorn bull was outstanding in the breed records. This was 'Tickford Sam', imported in 1920. He was used in the herd for 6 years and a progeny test of 6 daughter-dam pairs for 25 lactations showed that he was responsible for an improvement in milk yields:

Average mature yield of daughters	6,126
Average mature yield of dams	5,328
Difference	+ 798 lb.

After his death no pure-bred bulls were used for any length of time until 1935, when 'Iford Ambassador 5th' was imported. Only 4 daughter-dam pairs are, however, available, though 16 lactations are compared, as follows:

Average mature yield of daughters	10,240
Average mature yield of dams	9,449
Difference	+ 791 lb.

The third imported Dairy Shorthorn bull to be used was 'Chalfield Minstrel 2nd', which was imported in 1936 and used until 1945. Though his record is not as good as the others, he left a number of daughters which have milked well. His record for 6 daughter-dam pairs and 14 lactations is as follows:

Average mature yield of daughters	9,481
Average mature yield of dams	10,016
Difference	− 535 lb.

Influence of age on lactation yield.—In Table 10 the average yields of cows for successive lactations are set out. The average yield is seen to have increased up to the 6th lactation, and then gradually decreased. The 5th to 7th lactations each averaged over 10,000 lb. The lactation period also tended to increase up to the 6th and 7th lactations.

TABLE 10. *The Influence of Age on Milk Yield*

Lactation	*No. of lactations*	*Average yield, lb.*	*Average no. days*
1st . .	32	6,453	322
2nd . .	25	8,052	299
3rd . .	19	9,124	311
4th . .	15	9,678	307
5th . .	15	10,231	329
6th . .	10	11,149	346
7th . .	7	10,564	343
8th . .	4	9,305	286
9th . .	2	8,736	292
10th . .	2	8,881	291
11th . .	1	7,633	316
12th . .	1	6,847	268

Interval between calves.—The usual practice in temperate zones is for cows to calve annually, and the interval between calving and fertile service (or service-period) must therefore not exceed 85 days. Figures obtained for four Milk Recording Societies in England, reported by Hammond [14], showed that the average service-period was 97 days. The range varied from 77 for spring calvers to 127 for autumn calvers. In a recent survey the Milk Marketing Board [15] obtained a figure of 394 days between calves, equivalent to a service-period of 111 days.

Records for all cows in the Athalassa herd in 1934, or those which calved subsequently, show a rough correlation between winter calvings and low service-period. The average service-period for 165 calvings was 113·5 days with a range from 138·5 for November calvings to 98 for June calvings. Forty per cent. of the calvings are for the period December to March, when the interval was from 103 to 106 days, compared with Sanders's standard of 85 days.

It is of interest to compare the figure of 113·5 days with that obtained in the tropics, where cattle tend to have a longer service-period than in temperate countries. Thus Edwards [16] reports that in Jamaica the average service-period for Jerseys was 196 days. This is equivalent to an interval of nearly 15½ months between calves, compared with 13 months in Cyprus and 12½–13 months in England and Wales.

Length of lactation.—Up to 1935 few lactations of over 300 days were recorded and the average length of lactation varied from 255 days (1925) to 314 (1931). Since 1935 the duration of lactation has increased, and in 1942 the average period was 357 days, the average for the 12 years, 1935–46, being 312 days. During this period 62 per cent. of the 133 lactations were between 276 and 350 days, 19 per cent. were less than

276 days, and 19 per cent. were over 350 days. Only 6·75 per cent. were longer than 400 days, due mainly to temporary sterility.

Month of calving.—The winter and spring months are the most suitable for calving as there is more green food available and the weather is cooler. Summer calvings (June–September) are avoided if possible owing to the extreme heat and added risk of infection at calving. The records, which go back for the older cows before 1935, show that there are two peak calving periods, December–January and April–May. There appeared to be no correlation, from the data available, between month of calving and lactation yields. Records of summer calvings are too few to make a comparison with winter and spring calvings practicable.

Wastage.—During the 12-year period 1935–46, out of 45 cows which calved at the Stock Farm 30 have been disposed of as follows (per cent.): (1) mastitis 17, (2) sterility (including 2 cows over 12 years) 17, (3) old age 10, (4) other causes 23, (5) disposals of surplus stock 33. Of these 30 cows, one-third either died or were destroyed and two-thirds were sold. Of the 'other causes' over half were the result of the animals eating nails or pieces of wire. Several cases of sterility occurred which responded to treatment.

Average lifetime of cows.—The average age of the 30 cows at disposal during the twelve years was 7·2 years; for those that either died or were sold on account of old age, sterility, &c. (66 per cent. of the total disposals), it was 8·5 years, whilst the average age of the surplus cows when sold was 4·6 years. These figures compare well with those obtained in England where the average lifetime of dairy cows is put at about 6 years.

Conclusions

The records obtained at the Government Stock Farm over a period of 12 years since accurate data were kept show that, notwithstanding the high summer temperatures and somewhat unfavourable climatic conditions, European dairy cattle will thrive and give yields of milk comparable with those obtained in temperate zones.

The increase in milk yield per cow at the Government Stock Farm has been striking, and the decision to concentrate on the Dairy Shorthorn breed has led to a more uniform type of cattle than existed before 1934. The Dairy Shorthorn breed was found to be superior to the South Devon, and with proper management average lactation yields of 8,500 to 9,500 lb. have been obtained. These compare favourably with published figures for Jewish settlements in Palestine, where conditions and management are considered to be somewhat similar. The average daily yield of milk per cow increased from under 15 lb. to over 27 lb. per day between 1921–5 and 1941–5.

There has not been any unfavourable effect on regularity of breeding, on length of lactation, or on stamina due to the climatic conditions subsisting in Cyprus. The length of lactation has increased, breeding difficulties have not been exceptional, and in particular the age to which cows lived was high (7·2 years for all cows disposed of). Eighty per cent. of the cows in the herd gave milk containing from 3 to 4 per cent. of butter-fat. The herd average from 1935 to 1946 varied from 3·43 to 4·06 per cent.

It must, however, be emphasized that the yields and data recorded here were obtained under specially good conditions of feeding and management and are not applicable to the island generally. That there is a growing demand for cow's milk and an increasingly important cattle-dairying industry in Cyprus is shown by the steady demand for cattle and the increasing use made of government-owned bulls. Nevertheless, this industry is still in its infancy and caters only for a small section of the population. War-time changes in habits and in prices have been partly responsible for the demand for cow's milk, but it is important to remember that the rural population does not drink cow's milk, except in isolated cases, and that yaourt and other foods prepared from milk usually take the place of pure milk in their diet. Moreover, these are made principally from sheep's and goat's milk. The 'tethered' or domestic goat in fact replaces the cow in most rural areas as the source of milk for the household. The economics of cow's-milk production must be considered if the development of the dairy cattle industry is to be encouraged.

The evidence is, therefore, that the Mediterranean climate in Cyprus is not unfavourable to the successful breeding of dairy cattle, and that no degeneration has taken place. Though grading-up the native cattle has been successfully carried out in Palestine it has not been attempted in Cyprus and it seems preferable to continue to build up dairy stock with the help of occasional importations but without recourse to a general system of grading-up.

One final conclusion may be drawn: in any programme of breeding-work in an area such as Cyprus it is essential to decide after preliminary investigation what policy is to be adopted and then to adhere strictly to that policy. To switch from one breed to another at short intervals is bound to lead to a confused mixture of stock and to retard progress. At the same time no breeding programme can succeed without a proper and sustained level of management and proper records. These are points which have too often been overlooked in the improvement of livestock in the past.

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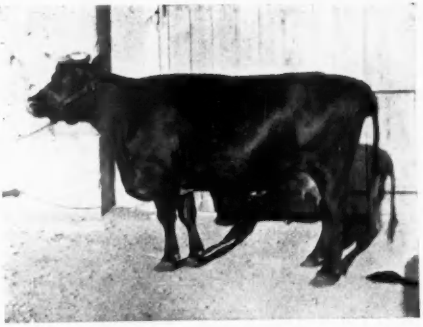
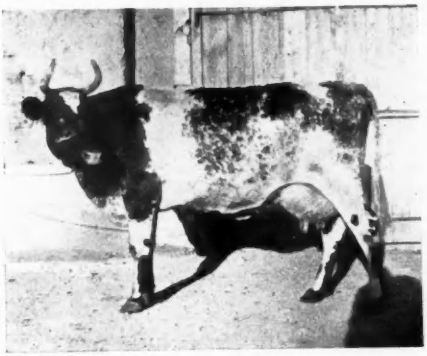
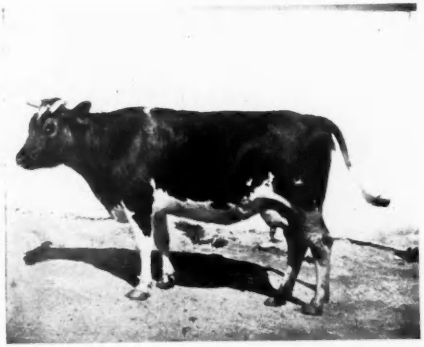


1. Dairy Shorthorn cow bred in Cyprus. Gave 9,805 lb. milk in 296 days (3·8% fat) in her 3rd lactation



2. 3/4-bred Dairy Shorthorn (1/4 Ayrshire). Gave 11,866 lb. milk in 296 days (3·65% fat) in her 3rd lactation



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THE RELATION BETWEEN THE SIZE OF FIELDS AND THE SPREAD OF PLANT-DISEASE INTO THEM

PART I. CROWD DISEASES

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THE questions raised here concern the effect of the size of fields on the amount of plant-disease entering them. Will the amount of disease be affected by making fields larger and proportionately fewer and farther between? If a country grows a million acres of wheat, will the prevalence of rust be affected by whether fields are on the average 10 acres or 100? Questions of this sort have been pertinent since cultivation began. They reached a new level of significance when collective farms and state farms were established in the U.S.S.R., but it seems that large fields were considered there largely from the angles of economics and agricultural engineering. Now large fields have come to Africa, the groundnut scheme involves units of tens of thousands of acres, and there is other mention of mechanized farming to raise the standard of living above the subsistence level of peasant agriculture. It is proposed to show that in the planning of this new agriculture plant pathology has a place next to these two sciences. The suggestion will be offered that largeness of field may in itself be made the primary means of controlling some of the more important diseases, not only of groundnuts but also of food crops like sweet-potatoes, cassava, and maize; and consequently that in a system of farming large fields a re-orientation of outlook on plant-disease is needed.

The matter will be presented in three parts. In Part I the attempt is made to ascertain general principles, without thought of special applications: it deals with crowd diseases, which we define as diseases which neither spread far in considerable amount nor persist long in the soil. The problem in its simplest form is illustrated by the finding of Wellman [1] in Florida that cucumber mosaic virus causing mosaic in celery comes from alternate hosts like *Commelina nudiflora* growing within 75 ft. of the field. For argument, accept this figure, and, because infection does not travel far, neglect the possibility of vectors flying right over the field without settling in it. The area of the 75-ft. zone about a square field of 0·1 acre is 0·86 acre; about a square field of 1 acre it is 1·85 acres; and about a square field of 10 acres it is 4·95 acres (Fig. 1). Thus 10 acres of celery, divided into a hundred square fields of 0·1 acre, would draw infection from alternate hosts scattered over 86 acres; divided into ten 1-acre fields, from alternate hosts scattered over 18·5 acres; and concentrated into one single square field of 10 acres, from alternate hosts scattered over only 4·95 acres. Mere concentration of fields brings down the source of infection sharply.[1] The simplicity of this illustration

[1] Strictly, what Wellman's results show is that *most* of the infection comes from within 75 ft. of the field; and what our arithmetic shows is that concentration brings down sharply the source of *most* of the infection. The point is not worth pursuing here.

is typical of crowd diseases, and our aim in Part I is at a fuller understanding of these diseases. We must describe the characteristics of crowd diseases; suggest why most virus diseases seem to be crowd diseases; ascertain the relation between isolation and enlargement of fields as a method of control; and determine the effect of making a field larger on the amount of infection it receives from its surroundings, and the effect of making fields larger and proportionately fewer on the interchange of infection between them. To keep the discussion within

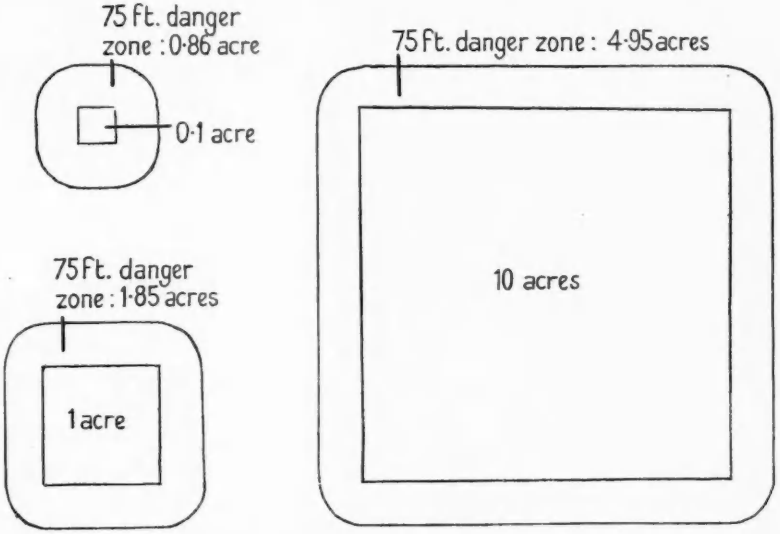

FIG. 1. A representation of Wellman's finding that cucumber mosaic virus enters a field of celery from alternate hosts within 75 ft. of its edge.

bounds, the examples in Part I are restricted, so far as possible, to the potato virus diseases; where other examples seem desirable, they are drawn for variety mostly from diseases of trees and bushes.

In a later paper we shall turn to fungus diseases spread by air-borne spores. This topic is at once both easier and more difficult than that in Part I: easier, because we shall be dealing with inanimate spores moving without volition, whereas many crowd diseases have insect vectors; and more difficult, because there is no restriction whatsoever on the distance over which a considerable amount of infection may travel. In a further paper we shall drop the attempt to examine the fundamental issues and make some suggestions about possible measures of control.

Two Properties of Crowd Diseases

1. *Control by mixed cropping.*—This is the property which gives the name, crowd disease: when susceptible plants are separated from one another by immune plants the spread of infection is greatly retarded.

A conspicuous example is provided by the 'native' potatoes of Basutoland. The chief vector of the potato viruses, *Myzus persicae*, is uncommonly abundant, possibly because its winter host, the peach, is almost ubiquitous. One would expect the potato virus diseases to spread rapidly, and this is so when the potatoes are planted, unmixed with other crops, in rows. But the usual way potatoes grow in Basutoland is as self-set groundkeepers in maize or other crops and in old fallow lands and abandoned fields. Here they are characteristically in a state of great dispersion and also in a state of perfect health. Varieties which have been in the territory for more than a hundred years are practically free from virus diseases, except when, as noted, they grow in rows or compact patches in kitchen gardens. Confirmatory evidence of the supposition that the Basutoland potatoes owe their health to dispersion was obtained near Pretoria, where it was possible greatly to retard the spread of leaf-roll virus and virus Y by planting potatoes dispersedly in isolated fields of maize in summer or peas in winter at the rate of a few hundred sets per acre. Further evidence comes from Rothamsted where Bawden [2] noticed that isolated self-set potato plants growing among crops like cereals do not contract virus diseases at all rapidly.

The measure of control afforded by dispersion follows naturally from the fact that crowd diseases, by definition, do not spread far in considerable amount. There is a tendency towards pockets of disease, as a result of infection falling off sharply as the distance from its source increases. For example, Murphy and Loughnane [3], working on the spread of leaf-roll virus within potato fields in Ireland, found that in an average year no plant separated from the source of infection by less than 80 in. along, or 50 in. across, the drill is likely to escape infection, and none separated from the source by more than 21 ft. along, or 10½ ft. across, likely to take it. Plant-to-plant spread, often coupled with less frequent spread over greater distances, is also characteristic of tea phloem necrosis virus [4], the viruses of cocoa [5, 6], and of many other woody and herbaceous plants.

About the name, crowd disease, it might be added that most diseases, including fungus diseases, are probably favoured by crowding, but there is this difference from the diseases we are discussing that their existence is not so dependent on it. In Basutoland *Alternaria solani*, for example, readily attacks potatoes, despite their dispersion and the absence of alternate hosts.

2. *Control by isolation of fields.*—The isolation of fields for the maintenance of health is too frequent a recommendation for virus diseases to need much comment here. One example has already been quoted: that of fields of celery in Florida which are satisfactorily protected against cucumber mosaic virus by removing alternate hosts for a distance of 75 ft. around them [1]. To give an example for trees, peach orchards in the eastern areas of the U.S.A. can be protected from peach X-disease virus by destroying *Prunus virginiana* within 200 ft. of them [7].

The distances which make for effective isolation are to a great extent governed by climate. A cool, moist atmosphere reduces the flight of the aphis *Myzus persicae*, so that in countries with cool maritime climates the

movement of potato virus diseases between fields receives relatively less attention, and the presence of sources of infection within fields, like groundkeepers or infected seed, relatively more attention than in continental climates. Isolation is so much more effective in cool maritime climates that it is to a great extent taken for granted; and thus it is that the literature of the process of isolation is considerably greater from Maine, for example, than from Britain.

Relativity in isolation; sporadic outbreaks at a distance.—The distance over which considerable infection will travel depends not only on the gradient of infection away from its source but also on the amount of infection released at the source. A distance of a few yards, or tens of yards, may suffice effectively to isolate single plants from one another, as in mixed cropping, whereas with the same disease considerable infection may travel hundreds or thousands of yards when its source is a large field of thousands of diseased plants. This must be kept in mind when interpreting the definition of a crowd disease as one in which infection does not travel far in considerable amount.

Because infection generally grades away from its source without abrupt discontinuities, one can rarely fix the distance from the source within which *all* infection will fall. When, to repeat an old illustration, we say that *most* cucumber mosaic virus is not carried farther than 75 ft. from the weeds serving as its source, this does not exclude the possibility that a little will be carried 750 ft. or more. For this reason sporadic outbreaks of disease fairly far from the source of infection are in no way unexpected with crowd diseases; but they must be sporadic and not common.[1]

Virus Diseases as Crowd Diseases

Relatively inefficient dispersal of viruses.—The first essential of a crowd disease, that infection does not spread far in considerable amount, depends, as we have just noted, on the form of the gradient of infection away from its source and on the amount of infection released at the source. As to the gradient, one infers that it must be very steep when infection ordinarily spreads only by direct contact between plants, as many viruses, like potato virus X, do. As to the amount of infection released at its source, one observes that, whereas many fungi inhabiting the aerial parts of plants have effective mechanisms for getting spores into the air at the right time and the proportion of fungus substance converted into spores is not inconsiderable, the viruses, probably in consequence of their pattern of systemic parasitism, are largely, and in a few instances wholly, plant-bound. A few viruses, like potato paracrinkle virus or laburnum or privet variegation viruses, which can be transmitted only by grafting or budding, live and die with the clone they inhabit, without ever escaping in nature to infect other clones. With most of the other viruses, even those spread by vectors, the arrangements for spreading are very haphazard by comparison with those of the fungi,

[1] The difference between the frequent dispersal over short distances and the less frequent dispersal over long distances is heightened when infection is carried by vectors with both wingless and winged phases.

and the proportion of their substance which escapes is very small. If there are any who consider that viruses are spread with a high degree of efficiency when they have an insect vector, they might ponder the difference between, for example, blight and the aphis-borne virus diseases of the potato. The means of dissemination and multiplication of Phytophthora are so effective that a single blighted shoot can ultimately bring about the infection of thousands of plants before the season is over, the weather being favourable and no fungicides being used; but even under the most propitious circumstances the number of virus-diseased plants rarely increases more than fortyfold during a season.

The second essential of a crowd disease, that infection does not persist long in the soil (or in plant-residues in the soil), is also characteristic of most plant-virus diseases, for most viruses do not long survive the death of their hosts.

Exceptions among the virus diseases.—There are virus diseases which cannot be classed as crowd diseases. The causal viruses fall into at least four classes:

1. Viruses which persist in the soil, like wheat mosaic virus.

2. Tobacco mosaic virus which, apart from persisting in the soil for years, has a vector, man, who does not follow the rules.

3. Viruses with very active vectors. The thrips carrying tomato spotted-wilt virus is often very active in hot climates and (it seems) often travels far when it takes to the wing. Whereas (as we have noted in the paragraphs dealing with mixed cropping) there is a tendency for virus diseases to occur in pockets as infection spreads to plants in the close neighbourhood of its source, tomatoes infected with spotted wilt often occur quite randomly within a field, without any evidence of neighbour-to-neighbour infection. This has been shown by Bald [8] in Australia, and is a regular feature of the disease in South Africa.

4. Viruses in vectors driven long distances in search of food. There are times when vectors migrate in mass over considerable distances as a result of their host plants dying or becoming unpalatable. The leaf-hopper carrying beet curly-top virus in the western part of the U.S.A. is a well-studied example. In all probability, examples of this sort are common in irrigation areas where crops under water must often appear to insects as oases among parched vegetation.

The Relation between Isolation and Enlargement of Fields as a Method of Control

The relation may be summarized in a theorem which is thought to be true in all circumstances for all diseases, whether they are caused by fungi, bacteria, or viruses. It is: *If disease entering fields can easily be controlled by isolation, it can also be controlled by making the fields larger and proportionately fewer.*

This theorem allows the process of enlarging fields, of which the literature is meagre, to be linked to the process of isolation, of which the literature, though scattered, is extensive.

Both isolation and enlargement of fields require practically identical conditions to be effective as methods of control. Both methods are

effective only against infection (or insects capable of acquiring and transmitting infection) entering fields from without. Neither method is likely to avail much against infection that travels far in considerable amounts, or against infection persisting in the soil at the time of planting. Neither method avails much against infection that multiplies very rapidly within the field; for then even a reduced amount of infection entering the field may be dangerous. For much the same reason, neither method is as useful with perennial crops as with annuals, because even a few sporadic infections entering a perennial crop may multiply to dangerous proportions in the course of years. Unless the distance over which infection can spread is very short indeed, it is only when the infection cannot spread within the crop[1] that either method is really effective for perennial crops. Two cases call for special discussion:

1. *Infection enters from uncultivated plants outside the field.*—The connexion here between isolation and the enlargement of fields has already been illustrated in Fig. 1. Wellman's [1] finding that celery could adequately be protected against cucumber mosaic virus by destroying alternate hosts within 75 ft. of the field, a typical process of isolation, was turned to show that control should also be possible by making the fields larger and correspondingly fewer.

Control by this means is possible in all but the smallest fields—fields so small that infection can easily pass over them from side to side; but, as reference to Fig. 1 will show, it is not until the dimensions of the fields are large by comparison with the distance over which considerable infection can travel that the relation between the size of the fields and the amount of infection entering them becomes very simple. With these comparatively large fields, represented by the 10-acre field in Fig. 1, the danger-zone surrounding the field is roughly proportional to the perimeter of the field. At this stage the average amount of infection entering unit area of the field (per acre, for example) is approximately inversely proportional to the square root of the whole area of the field, other factors like shape and aspect being constant. The larger the field, the better the approximation; when dealing with compact fields of thousands or tens of thousands of acres, the concept of infection from the perimeter must become fairly exact for all diseases which do not easily spread far.

2. *Infection moves from field to field.*—In this case making fields larger and proportionately fewer involves three factors, all of which can be expected to be effective only when isolation is effective.

The first is the same as the one just considered, and is therefore bound up with the process of isolation in the same way. When the distance over which considerable infection can move is small by comparison with the dimensions of the field it enters, the danger of infection is from around the perimeter, with consequences already stated.

[1] As an example, the rust fungus, *Cronartium ribicola*, spreads from Ribes to pine, but not from pine to pine. Isolation of pine forests by the destruction of Ribes in the vicinity is a well-established method of control, in every way parallel to the destruction of alternate hosts of cucumber mosaic virus in the vicinity of celery fields: our previous illustration.

The second is the same as the first viewed from the opposite angle: it is the escape of infection from diseased fields. If the dimensions of the diseased fields are large by comparison with the distance over which a considerable proportion of infection can travel, the infection which leaves the field leaves from near the perimeter.

The third is an isolation factor pure and simple. When fields are made larger and proportionately fewer, they are also made farther between, the average distance between fields increasing in proportion to the square root of the average area of the fields. How increasing the distance between fields will affect the movement of disease from one to the other must depend on circumstances (e.g., if infection has a vector, on whether the vector flies or crawls or hops, on whether there are alternate food-plants between the fields on which the vector is likely to stop, and so on). Quantitative generalizations are therefore out of the question.

Because no generalizations are possible, one cannot estimate the whole effect of making fields larger and correspondingly fewer on the movement of infection between them. All that one can predict is that the benefit of enlargement is greater when infection comes from other fields than when it comes from uncultivated plants around the fields; that is, the response to enlargement will be greater than that predicted by the inverse square-root relationship for simple perimeter infection.

Verification of these deductions is difficult, because a whole countryside is needed as an experimental unit. One incomplete example can be quoted. During extensive experiments in Maine, Folsom [9] measured the increase of mosaic (crinkle) in potato-seed plots during the season, the increase being mostly the result of infection coming *into* the plots from other fields. In all 5 years the increase was greater in small plots of less than 1 acre than in plots of more.[1] Folsom comments on the 1937 results in particular. In that year 'there was a difference between small and large seed-plots as to the proportion planted tuber-unit, but in spite of the smaller ones being tuber-unit[2] and therefore better rogued, stocks replanted from them showed over twice as much mosaic as the replanted stocks from the larger plots, mostly bulk planted'. The average size of the 11 small plots was 0·37 acre; of the 16 large plots, 1·61 acres. The experiment is incomplete for our purpose, because the effect determined was of the size of individual fields, whereas our discussion is about making all fields larger and proportionately fewer; only the first of the three factors we have mentioned is likely to have been involved in the result, which consequently can only show part of the expected effect.

[1] In no one year was the correlation between the size of the plot and the amount of mosaic in replanted stocks significant, but if all 5 years' results are taken together the difference between small and large plots is highly significant. Thus, in 1933 the amount of mosaic in stocks replanted from plots of less than 1 acre was 2·21 per cent., and from plots of more than 1 acre 0·93 per cent., a relative reduction of 58 per cent. In 1935 (no figures were given for 1934) the relative percentage reduction was 92; in 1936, 20; in 1937, 56; and in 1938, 72; which gives a mean relative reduction for the 5 years of 59·6 per cent. This is significantly different from zero: $t = 5{\cdot}05$, $n = 4$, $P < 0{\cdot}01$.

[2] In tuber-uniting, all the pieces cut from a single tuber are planted next to one another.

With leaf-roll, Folsom's results were inconclusive, the results being complicated by differences in locality, time of planting, isolation, &c. Significant differences between averages were difficult to find because of the small number of plots characterized by any one combination of conditions. But where he was able to disclose differences in his Table 14, p. 236 (but not to exclude the possibility of spurious correlation), smallness of size of seed-plot regularly contributed to increase of leaf-roll.

The Need of Homogeneity

The benefit of making fields larger and correspondingly fewer is conditional on the fields remaining homogeneous with respect to disease when they are enlarged.

An example will suffice. A farmer saves enough partly infected potato seed to plant 4 acres. He also buys enough healthy seed for 4 acres, and from this he hopes to save some seed for the following year. His best plan, which permits maximum isolation and reduces to a minimum the amount of infection the healthy crop will receive from the diseased, is to plant all his own saved seed in one compact 4-acre field and all the healthy seed in another. This is safer than dividing the seed among many small scattered fields. But the very worst procedure would be to plant all the seed together in a single heterogeneous 8-acre block. The 4-acre fields are the largest he can plant in the interest of hygiene, because they are the largest which can remain homogeneous.

Effect of the Size of Field on the Multiplication of Infection within It

The question arises whether, when fields are made larger and correspondingly fewer, the reduction in the movement of disease between fields is not offset to some extent by an increased rate of multiplication within them; whether the reduction is in fact a net gain. It might be argued that when disease is present within a field, making the field larger would allow greater scope for multiplication. But the evidence is against this. If it were true that by bringing more diseased plants together in larger fields the rate of multiplication would be increased, it would follow that the rate would be at its highest in the centre of the field; i.e. that the proportion of diseased plants would increase inwards from the edge of the field. One does sometimes find that the outer row has less disease, because it is exposed to infection from one side only. The effect may even extend a little deeper. For example, Thomas *et al.* [10] found that peach yellow-bud mosaic, a typical crowd disease, occurred less in the outside row or two than in the rest of the orchard, when infection multiplied within and the orchard was not exposed to infection from without. (Their explanation, that the hypothetical vector shuns the outer rows, is both unlikely and uncalled for.) But the effect never goes very deep; and a study of published charts of orchards and fields, as well as of our own data, gives no indication of any special tendency for crowd diseases to accumulate towards the centre fields. We therefore conclude that (except for very small plots in which the

lesser vulnerability of the outside row or two would be of some consequence) the effect of the size of the field on the rate of multiplication within is negligible.

Summary

The problem is to determine how making fields larger and correspondingly fewer affects the amount of infection entering them. This paper is confined to a discussion of crowd diseases, which are defined as diseases caused by infection which neither travels far in considerable amounts nor persists long in the soil. Many virus diseases are crowd diseases, probably because the viruses are to a great extent plant-bound.

The first case discussed is that of infection coming into a field from uncultivated plants in the surroundings, as cucumber mosaic virus comes from weeds like *Commelina nudiflora*. As fields are made larger and correspondingly fewer without change of shape or aspect, the amount of infection entering per acre is approximately inversely proportional to the square root of the area of the fields, an approximation which becomes increasingly accurate as the dimensions of the fields become large in relation to the distance over which considerable infection can travel.

The second case is that of infection moving from field to field. No generalization is possible other than that the effect of making fields larger and correspondingly fewer on the amount of infection entering unit area of them is greater than in the previous case. As evidence for a considerable effect of the size of field, the results of Folsom with potato mosaic are cited.

Whether the reduction in the amount of infection entering unit area of field can be used to advantage may be judged by the theorem that if disease entering fields can easily be controlled by isolation, it can also be controlled by making the fields larger and proportionately fewer.

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SUGAR-CANE VARIETIES IN BRITISH GUIANA: AN HISTORICAL REVIEW

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Introductory.—Sugar has been manufactured for export in British Guiana for almost 300 years, and is now the most important of the colony's agricultural industries. Considerable changes have taken place during this time, not only in the methods of sugar manufacture, where development has been made from the original hand-operated mills in use before 1664 to the central factories of to-day, but also in the agricultural methods employed, and in the sugar-cane varieties grown. The raw material of sugar manufacture is the plant itself, and though improvement has taken place from time to time as different varieties became available, it is only within comparatively recent years that the attention of scientists has been directed towards its improvement by intensive breeding. The results already achieved, and to which reference is made later in this paper, have been phenomenal. It is less than 60 years since organized research was started: previously it was thought that sugar-cane flowers did not produce viable seed, and that experimental breeding was therefore impossible, so that reliance had to be placed on the naturally occurring forms of the plant for commercial growing. In British Guiana, therefore, as in other sugar-cane-growing countries, a history of the varieties grown tells of long periods devoted to the cultivation of original variety types until the introduction of seedling varieties at the beginning of this century. The present account of varieties in British Guiana is based on such data as are available, both published and unpublished, in the records of the Department of Agriculture. Standard works of reference and original papers have also been consulted. Unfortunately, the information concerning the early days is meagre. The actual date of introduction of the plant is not known with certainty, and only an approximation can be given for the beginning of the era of the Bourbon or Otaheite cane, which was grown almost exclusively for more than 100 years. Nevertheless, the general picture is clear, and it is of some interest to trace the changes which have taken place in the variety situation during the long history of sugar production in the colony.

The Creole cane.—It is now well established that no form of sugar-cane is indigenous to the New World. The cultivated types have been traced to two distinct sources of origin: the thin Indian canes to the region around the head of the Bay of Bengal, and the thick so-called 'noble canes' (*Saccharum officinarum*) to southern Asia and the chains of islands in the Indian and Pacific Oceans. Cytological evidence was brought forward by Bremer in 1932 to support his view that the Creole cane, which he recognized as identical with the 'Puri' cane of India and the 'Geel Egyptish riet', or Yellow Egyptian cane of Java, arose as a hybrid between an Indian cane (*Saccharum barberi*) of the Mungo group

and a weak noble cane. The Creole cane reached southern Spain in the eighth century with the westward spread of civilization. It was still cultivated there within recent years to some extent for chewing, for included among varieties imported into the United States of America from Spain in 1935 was a small, soft, yellow cane known as 'Algarobena', which was shown to be identical with the Creole cane of the New World, or the 'Cana Criolla' as it is known in the Latin-American countries [1].

Columbus took the sugar-cane to the New World from the Canary Islands on his second voyage in 1493, and the first West Indian sugar was made in San Domingo in 1509. The Creole cane was the only form grown in the Western Hemisphere for about 250 years. It reached Brazil in 1532 and Peru in 1533 [2].

In what is now British Guiana the first organized settlement was made by the Dutch about 1620. They first turned their attention to growing tobacco, and the extent to which the industry flourished in those early years is indicated by the fact that 28,000 lb. of this commodity were exported to England in 1623.

The sugar-cane was probably brought from Brazil in 1658 by a party of Dutch Jews who settled in the Pomeroon district in that year, following the loss of Brazil by the Dutch. At any rate, sugar from the Pomeroon was offered for sale in Middelburg, Holland, in 1661, though there might have been previous exports, to which no reference has been found [3]. The new industry progressed favourably as the Dutch drained the coastal lands and brought them into cultivation. In 1669, 60,000 lb. of sugar were exported to Zeeland, and by 1749 eight ships were required to carry the cargo of 1,400 tons to the same destination. By this time, sugar-cane was also cultivated in other districts of what is now British Guiana. In 1674 there were five plantations in Berbice, and the Essequibo area had produced sugar for some years. In the Demerara district, cultivation of the cane was not begun until considerably later: even in 1797 Plantation Kitty, near to where Georgetown is now situated, was the only one growing sugar-cane. All other plantations on the east-coast section were growing cotton at that time.

The Creole cane was short-jointed, greenish ripening to yellowish, and sometimes blotched with red when exposed to the sun. Jenman described it in British Guiana in 1887 as 'not stouter than a stout walking stick, with very numerous erect shoots, uniform in size'. In comparison with 45 other varieties described and analysed in the same year, it was found to be of relatively very high fibre-content and of good juice-quality. The average results of 4 years' experiments carried out in the Botanic Gardens, and published in 1891, some hundred years after the Bourbon cane had superseded the Creole as a standard estate variety, served to corroborate this previous analysis. It is recorded that the Creole cane was among the richest of the varieties available at the time. In commenting on the results, however, Jenman observed that the Creole cane, in spite of its excellent juice-quality, was not only comparatively small, but yielded as a rule only an average number of canes to each stool, and was therefore unfit for cultivation as a sugar-producing variety. This observation does serve to show that it was on account of its

inferior yielding capacity in the field in comparison with the noble canes, rather than of any inferiority in its quality of juice, that the Creole cane fell from popularity.

The last record of the occurrence of the Creole cane in British Guiana is that in 1892 the canes in both of the duplicate plots of this variety at the Botanic Gardens died out before they could be reaped.

It is necessary to emphasize that the Creole cane under consideration is the original introduction from the Old World, which had spread westward from India and China, having been grown in those countries as far back as history records. This emphasis is necessary because of the confusion in nomenclature that is found in the literature of all sugar-cane-growing countries. In British Guiana some other varieties have been known as 'Creole' from time to time. In 1884 a purple cane was imported from Australia under this name, a variety that appears to have been one of the Cheribon series. Also at about the same time there are frequent references to the growth and analysis of a 'Creole' cane which is undoubtedly the Bourbon or Otaheite variety. Similarly, in 1888 Jenman recorded that the Otaheite was known as 'Creole' in St. Kitts. Other misapplications of the name, in various countries, are given by Noel Deerr [4]. In the West Indies and British Guiana it is not difficult to understand how a variety which had been long in cultivation should come to be known by this name, for to this day the term is generally applied to animals and people raised in the colonies of the Caribbean.

The Bourbon or Otaheite cane.—This cane superseded the Creole in British Guiana, as in the West Indian islands generally, and was the standard estate variety until early in the present century. It has not been possible to establish accurately the date of its first introduction. Jenman, speculating upon this point, wrote in 1885: 'How or when it was introduced I have not been able to gather.' In his report for 1890 he records that the Bourbon together with the Cheribon canes (which are considered below) 'seem to have reached the West Indies, possibly together, before the end of the last century', although later in the same report he refers to the Cheribon canes as 'among the earliest canes cultivated here, having been introduced from the East about the middle of the last century by the Dutch'.

It is known that the Bourbon cane reached French Guiana about 1790, having been introduced by the French Government, together with the Cheribon canes, from Mauritius through the influence of Cossigny, who had been responsible for variety introductions to that country direct from Java [4]. The Bourbon cane was well established in Mauritius at that time, having been the first variety to be imported into the colony in 1650 [2].

Another possible source of introduction of the Bourbon cane to British Guiana is from the historic voyage of Captain Bligh in 1791. Bligh is known to have brought the Bourbon cane, among others, direct from the island of Otaheite to Jamaica, from whence it spread to the other West Indian islands and the mainland of South America. Noel Deerr indicates definitely that one introduction to British Guiana was from this source. He says: 'The variety spread rapidly to other

districts' (from Jamaica) 'being brought to Cuba by Arango in 1795, to Trinidad by Begorrat in 1792, to Barbados by Firebrace in 1796, to Demerara in the same year, to Louisiana in 1797, and to Spain in 1816' [4]. It is impossible to say, however, whether this was the first introduction of the variety to the colony.

In comparison with the Creole cane, the Bourbon was found to yield a far better tonnage in the field, to ratoon well, and to be a better factory cane. It soon became the most popular estate variety, and was planted almost to the exclusion of all other canes until the early years of the present century. It was evidently better suited to the conditions in British Guiana than were the Cheribon canes, which were introduced at about the same time but never achieved considerable commercial popularity.

Jenman made a careful description of all the sugar-cane varieties in the collection at the Botanic Gardens, Georgetown, in 1887, and also had comparative analyses made at the laboratory. The Bourbon was described as follows: 'Canes few or several, spreading, when mature often trailing, of average length, girth, and inter-joints; nodes constricted, edged, buds superficial, the internodes expanded; colour yellowish but variable, often green, when sun-exposed blotched with red on the upper side; few growing shoots at maturity; foliage withered after drought.' The results of analyses showed it to be about average as regards the percentage of sugar in the canes, and of rather low fibre-content.

One of the most interesting features of a study of the Bourbon or Otaheite cane in the several sugar-cane-growing countries where it was the most important variety for so long a period is its sudden failure in so many of them at about the same time. The first case of such failure on record is that in Mauritius about 1840 [2]. It failed also in Brazil about 1860, in Puerto Rico in 1872, and in other West Indian islands about 1890–5. In British Guiana the course of the fall of the Bourbon cane from commercial popularity can be traced in the available records. In 1893 Harrison and Jenman reported the results of an experiment in which 40 named varieties at the Botanic Gardens were compared with Bourbon, in yield and juice-quality, from 1886 to 1892. Their conclusions were summarized as follows: 'It is gratifying to find that the results of this series of experiments unmistakably point to the fact that the Bourbon is undoubtedly the best variety for cultivation, having regard to the conditions of our soil, seasons and climate.' Work with seedling canes was also being actively pursued at that time, and although a few promising seedlings had been bred (including the future standard variety of the colony—D. 625, bred in 1892) there was none that could be confidently recommended to give better results than the Bourbon. In the following year, 1894, 10 varieties exceeded the Bourbon in yield at the Botanic Gardens, and it was noticed that many Bourbon canes were diseased, and sometimes whole stools had died out. Other varieties were affected, but to a far less extent. Diseased Bourbon canes were also received for examination from plantations in the Demerara and Essequibo districts. In 1895 disease was causing considerable damage in widely separated areas of NW. Essequibo, the Essequibo islands, and the east

and west coasts of Demerara. The Berbice district was the last to be affected, for the report written in 1896 states that there was no material prevalence of the disease in the plantations there. As a point of historical interest, and one which Harrison and Jenman considered in relation to the control of disease in the field, it is recorded that in that year it was a common practice to burn the fields before reaping. Burning of the canes was not at that time carried out on the coast lands of Demerara and Essequibo, but was introduced at a later date, and is now the usual practice throughout the colony.

Although the Bourbon cane was recognized as highly susceptible to the disease, its replacement by other varieties was rather slow, no doubt because the outbreaks, though serious, were sporadically distributed; and it was frequently noticed that ratoons from fields heavily diseased before cutting grew away clean and healthy. The cause of the disease was in dispute until Howard's work in Barbados in 1903 showed the part played by the fungus *Colletotrichum falcatum*, and planters in British Guiana, loth to abandon their old favourite, continued to plant a considerable proportion of their lands in the Bourbon cane for many years in the hope that a natural recovery would take place.

In 1902 only 6,275 acres were planted in varieties other than Bourbon. Of this total, 1,889 were occupied by White Transparent (or Light Cheribon), and the remainder almost entirely by seedling canes, of which D. 625 represented 79 acres. In subsequent years, when the superiority of the seedling varieties came to be more fully recognized, the replacement of the Bourbon cane was more rapid. It still occupied 35 per cent. of the cane area in 1910, and as late as 1921 it still had its adherents. It was registered as 13 per cent. of the crop in that year, though it appears that the figure might be too high, as many of the Bourbon fields were mixed with seedling varieties. Crabtree wrote in that year: 'Probably the Bourbon in spite of its quality when grown under the best conditions would have been completely abandoned by now, but for a certain amount of sentimental attachment of some of the older school, who apparently live in hopes of a rejuvenation of this variety' [5].

The confusion in variety nomenclature in different countries also applies to the Bourbon cane in British Guiana; six different names were given to it in the collection of varieties assembled at the Botanic Gardens in 1890. Apart from the original introduction in the eighteenth century, it was received from Kew in 1881 under the name of Singapore, presumably on account of the origin of the Kew material. An introduction from Hawaii in the same year might have been the same cane, judging from the published descriptions. It was received from Queensland in 1884 under the name Lahaina, and from Mauritius in 1885 as Cuban and as China II. The Mauritius canes were from the collection imported into that country from Hawaii by Horne in 1879 [2].

The occurrence of a cycle of striped and self-coloured forms is typical of the older variety types of sugar-cane. The Lousier cane in Mauritius, which is synonymous with the Bourbon or Otaheite cane, arose as a bud-variation from the striped Mignonne variety [2]. In British Guiana

Harrison recognized the presence of striped variants in the Bourbon fields in 1902. He described such occurrences as not uncommon, though he had previously regarded them as representatives of the Green Ribbon variety, mixed with the Bourbon in the fields. A striped variety known as Horne, introduced among the collection from Mauritius in 1885, appears to have been a Bourbon-type cane.

The Cheribon canes.—In most sugar-producing countries these canes have been among the most important cultivated: they were at one time or another the standard varieties of the West Indies, Louisiana, Cuba, Mauritius, Java, and Mexico. British Guiana is an exception in this respect, for the Cheribon canes never represented a large proportion of the acreage planted. It was shown above that when the Bourbon cane fell from popularity owing to the spread of disease, the White Transparent (or Light Cheribon) was found to be much more resistant, and was propagated to some extent, but attention was at the same time focused on the new seedling varieties. The explanation why the Cheribon canes were not more important in British Guiana is to be found firstly in the relatively late arrival of the Bourbon disease, and secondly in the early success of Harrison and Jenman's work with locally bred seedlings.

Almost 1,900 acres were planted in White Transparent in 1902 and the figure had increased to 2,876 in 1904, but subsequently it decreased rapidly, and by 1911 was only 251 acres. The acreage was reduced to 14 in 1915, and there is no further mention of the variety in later records. Experiments with this variety, and with others of the Cheribon series, had been carried out almost continuously since 1887, but the Bourbon cane gave better results generally than all others until the appearance of the disease, and no other variety was planted to any great extent.

The Cheribon cane has existed in a cycle of striped and self-coloured forms—light and dark—since the earliest times. Rumpf's reference to the three Javan canes, yellow, purple, and striped, in the *Herbarium Ambionense* is the first known reference to sugar-cane varieties in any country [4], and there is now no doubt that the descriptions were of the Cheribon canes. These became widely distributed throughout the sugar-growing world under various names, frequently receiving different local names in each country where they were planted. As a result, the Cheribon canes, already existing in three distinct colour-variations, were being grown by the end of the nineteenth century under a considerable number of synonyms in the different sugar-producing areas. Only within recent times has this confusion in nomenclature been partly cleared up and the main variety types recognized. Even to-day many of Horne's canes of the Hawaiian and Fijian collections, introduced into Mauritius under their native names in 1878 [2] and from there to British Guiana in 1885, have not been assigned to one or other of the main recognizable original variety-types.

As early as 1887 Harrison and Jenman had established a collection of 47 named varieties at the Botanic Gardens, Georgetown, and they published detailed descriptions of each in the following year. In 1890, after study of these varieties, they recognized that the White Transparent was represented in the collection under 4 different names, the Purple

Transparent under 5, and the Red Ribbon under 3. It is now known that varieties grown in British Guiana under various other names belong to this important group.

The Light Cheribon has been grown in British Guiana at one time or another under 9 different variety names, as follows: White Transparent, Caledonian Queen, Rappoe, Mamuri, Bamboo, Hope, Java, Burke, and Meligeli. The Dark Cheribon has been known locally under 5 names—Purple Transparent, Java, Purple Mauritius, Queensland Creole, and Meera. Additional introductions from Louisiana in 1893 as Black Java and Louisiana Purple were destroyed after identification. The Striped Cheribon has been grown under the 3 names Red Ribbon, Striped Singapore, and Seete.

Other historical varieties in British Guiana.—The Salangore cane, which Wray described in 1848 from experience in the Straits Settlements as the finest in the world [6], was one of the earliest variety introductions into British Guiana after that of the original Creole cane. It was introduced from Jamaica about 1875 under the name of White Mauritius, presumably so called on account of having reached Jamaica from Mauritius, where it had long been known under the name of Penang [2]. It was recognized as being identical with the Salangore variety in British Guiana as early as 1888. This cane was never grown to any considerable extent commercially; although it often gave high cane yields, its juice-quality was poor and its performance erratic, characteristics which also precluded its large-scale cultivation in other parts of the world. It was re-introduced to British Guiana as 'Green Transparent' about 1896, and enjoyed a limited popularity on the 'Bourbon-sick' soils early in the present century. It is recorded that 5 acres were under Green Transparent in 1902, and this figure had increased to 750 by 1913. It reached a maximum of 1,495 acres in 1917, after which its popularity decreased and it was largely replaced by D. 625.

The Cavengerie cane, which is of New Caledonian origin, was received under the name Po-a-ole with the collection from Mauritius in 1885. Horne had introduced it into Mauritius from Hawaii in 1877–9 [2]. It was also received later, both from Jamaica and from Barbados, as Purple Mauritius, but was never grown commercially.

Another important original variety type, the Tanna or Caledonia cane, which was extensively grown in Mauritius, Fiji (as Malabar), Hawaii (as Yellow Caledonian) and elsewhere, is not mentioned in the British Guiana records, though one or more of its modifications might have been among the considerable collection of varieties in the Botanic Gardens from 1886 onwards, the majority of which were registered under native names from the countries of origin. It is certain, at all events, that the Tanna cane was never grown commercially.

The noble cane seedlings (*Saccharum officinarum*).—Harrison, who with Jenman was responsible for the early sugar-cane breeding work in British Guiana, had previously been associated with Bovell in Barbados in the re-discovery of the fertility of sugar-cane flowers in 1888. The occurrence of sugar-cane seed and its germination were reported independently from Java at about the same time. Harrison came to

British Guiana from Barbados in 1889: he introduced 12 of the earliest seedling canes from that colony, and immediately began work on sugar-cane breeding, which he continued until 1919. Jenman was associated with the work until his death in 1902.

Both in Barbados and in British Guiana, virtually all the early seedlings were of purely noble-cane origin, as breeding was carried out with the original varieties of the South Pacific *Saccharum officinarum* series. It is true that the Creole cane was probably of interspecific hybrid origin, but it was already superseded in commercial cultivation, and breeding work showed it to be practically infertile in British Guiana. Deliberate use of other Saccharum species in hybridization was not made in the West Indies and British Guiana until considerably later, though it had been first introduced by the Dutch in Java as early as 1893.

The most successful of Harrison's seedlings, so far as British Guiana is concerned, were D. 109, D. 145, and D. 625. The two former were raised in 1890, from open arrows of White Transparent and Red Ribbon respectively. D. 625, by far the most important of Harrison's seedlings, was raised in 1892 from an open arrow of a cane known locally as Dyer, a seedling variety bred in Barbados. Dyer has an interesting history. Among the twelve seedlings introduced from Barbados in 1889 was one called Morris, which was found to have been inadvertently mixed with canes of another variety before dispatch. Harrison separated the two varieties, and named the unknown one Dyer, after the Director of Kew Gardens at the time. In the report on the agricultural work in the Botanic Gardens for 1893–4–5 there is a note in Harrison's handwriting to the effect that both Morris and the variety received mixed with it (Dyer) were raised from arrow sowings of the Meligeli cane. It is evident, therefore, that D. 625 originated, through Dyer, from one of the Cheribon canes, forms of which were also parents of the varieties D. 109 and D. 145 mentioned above.

Of Harrison's 1890 seedlings, records of the 1893–4–5 crops show that D. 109 and D. 145 headed the list of canes that exceeded the Bourbon in yield, and it is noted that these varieties 'appear to be not alone of high value as plant-canes, but to greatly excel the Bourbon as ratoons'.

The year 1892 proved a good one for breeding work. Some 15,000 seedlings were obtained, but due to overcrowding in the boxes, damping-off, and insect pests, only 2,600 survived and were planted in the field. D. 625 was raised from a batch sown in October–November, of which 990 seedlings were pricked off into baskets, and of these, 575 failed soon afterwards, only 415 being planted in the field. Considering this high early mortality, it is perhaps fortuitous that D. 625 itself survived.

Harrison was extremely cautious in recommending his seedlings for commerical cultivation and it was only in 1901 that a number of them, including the three under reference, were regarded as being 'worthy of the attention of the Planters of the Colony for careful experimental cultivation'. The value of these seedling canes was shown within the next few years, and with the Bourbon failing there was a considerable variety-change within the early years of the century. The acreages

under Bourbon, D. 109, D. 145, and D. 625 from 1902 to 1918 are shown in the following table:

Year	*Bourbon*	*D. 109*	*D. 145*	*D. 625*
1902	66,048	1,727	442	79
1903	63,675	2,583	644	191
1904	60,977	3,338	902	537
1905	56,137	5,491	1,316	1,445
1906	50,910	8,386	1,842	3,357
1907	45,626	11,184	2,403	6,600
1908	38,134	9,908	3,284	9,664
1909	30,324	6,896	3,710	13,564
1910	28,823	4,063	4,229	16,650
1911	24,252	3,261	4,382	21,672
1912	22,403	2,548	4,618	23,669
1913	19,250	2,755	5,491	25,370
1914	18,633	2,272	6,071	32,686
1915	13,488	1,748	5,916	36,922
1916	9,109	1,725	6,088	37,174
1917	7,403	883	6,168	37,798
1918	4,950	320	5,920	36,000

In subsequent years D. 625 continued to increase in popularity. By 1924 it occupied 70 per cent. or more of the area under canes in the colony, and by 1929 this figure had increased to approximately 90 per cent., and D. 625 occupied the same pre-eminence in the industry that the Bourbon cane had at the turn of the century. At this time, however, another noble-cane variety Diamond 10, bred at Diamond Plantation from D. 145 (and therefore also a Cheribon derivative), was also increasing in popularity, and already occupied a considerable acreage, particularly along the banks of the Demerara river. Within the next few years, the area under Diamond 10 increased considerably, largely at the expense of D. 625. The acreages under these two varieties from 1933 to 1940 are shown below:

Year	*D. 625*	*Diamond 10*
1933	34,404	9,253
1934	32,429	13,304
1935	28,552	18,850
1936	21,380	23,700
1937	13,141	26,356
1938	4,938	26,865
1939	1,804	24,162
1940	382	20,263

Diamond 10 has continued to decrease in popularity, being largely replaced by the newer nobilized seedlings, but it still represented more than 20 per cent. of the area to be cut for the 1947 crop. It is the last of the noble-cane varieties to occupy any considerable acreage in British Guiana, and no others are likely to become important since the superior value of the new seedlings resulting from special lines of interspecific hybridization at the sugar-cane-breeding stations has been demonstrated.

Seedlings from nobilizations of S. spontaneum and S. barberi.—The production of interspecific hybrid varieties, obtained either by successive nobilization of wild Saccharum types or by inter-crossing of distinct nobilized strains, represents the major work of sugar-cane-breeding institutions at the present time. Many geneticists have abandoned the breeding of purely noble seedlings entirely. The term 'nobilization', originally used by the Dutch at the breeding station in Java, denotes the improvement of the hardy, disease-resistant but otherwise inferior Saccharum species by successive crossing and back-crossing to the noble canes (*S. officinarum*), so called on account of their comparatively aristocratic appearance and good juice-quality. Brandes and Sartoris refer to it as a happy selection of a term with definite connotations [1].

The first of the nobilized varieties to become commercially popular in British Guiana was the famous Javan seedling P.O.J. 2878, a third nobilization of the Javan form of *S. spontaneum* in the Kassoer blood-line, which was introduced from Trinidad in 1928. After a preliminary quarantine period it was multiplied for general distribution, and by 1930 every estate in the colony had received a small quantity of planting material. Variety trials carried out by the staff of the Sugar Experiment Station between 1932 and 1936 gave encouraging results, and in the latter year it was recommended that the acreage remaining under D. 625 should be entirely replaced by plantings of P.O.J. 2878 and Diamond 10, both of which were very popular at the time. P.O.J. 2878 had reached the position of the dominant variety in the Colony by 1938, when its acreage was greater than that of Diamond 10, and when these two varieties together occupied nearly 90 per cent. of the area under cane. The following table shows how P.O.J. 2878 continued to increase in importance until 1941; since then it has given way with increasing rapidity to newer and higher-yielding varieties:

Year	*Acreage of P.O.J. 2878*	*Percentage of total area planted*
1933	784	1·4
1934	2,764	4·7
1935	6,214	9·7
1936	12,427	19·2
1937	20,229	31·7
1938	28,232	45·7
1939	37,506	57·6
1940	42,961	66·0
1941	47,268	68·8
1942	46,179	68·0
1943	40,053	65·1
1944	32,901	54·8
1945	24,761	40·4
1946	17,433	27·6

The two Coimbatore seedlings Co. 419 and Co. 421 were introduced in 1937. After early promise in variety trials they began to reach commercial importance in 1942, and have been considerably extended since then. Co. 421 occupied more than 12,000 acres in 1946 and is at present

one of the most popular varieties in cultivation. It is a further nobilization of P.O.J. 2878, whilst Co. 419, which has not been so widely planted, largely on account of its comparatively low fibre-content, is of complex parentage, including the blood of *Saccharum barberi* and both the Javan and Indian forms of *S. spontaneum* as well as that of *S. officinarum*. D. 14/34, bred in British Guiana in 1934, began to reach prominence in commercial cultivation in 1944, and has been widely extended since that date, whilst B. 34104, bred at the British West Indies Central Sugar-cane

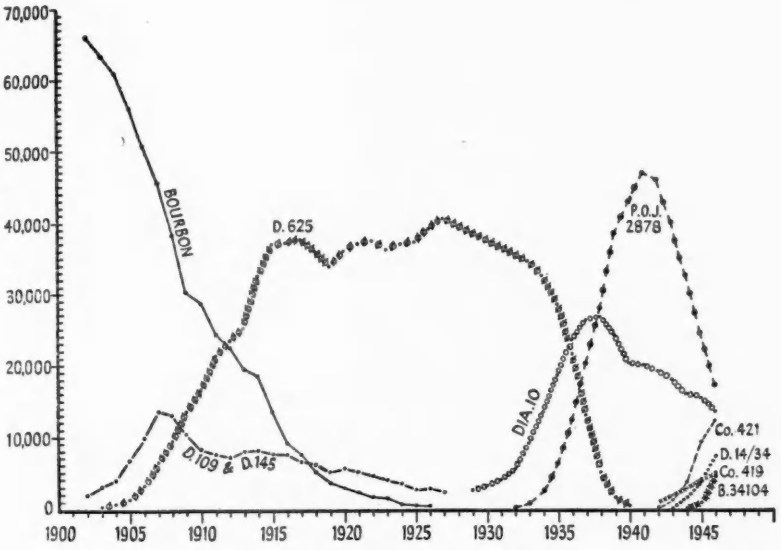

FIG. 1. Variety Acreages in British Guiana.

Breeding Station in Barbados and introduced to British Guiana in 1938, was the most recently introduced seedling to achieve considerable popularity. It has only been widely grown since 1945, but is being extended at present probably more rapidly than any other variety. Both D. 14/34 and B. 34104 are nobilizations of Co. 281, and therefore are descended from *S. barberi*, the Indian form of *S. spontaneum*, and the noble canes (*S. officinarum*).

The acreages under Co. 419, Co. 421, D. 14/34, and B. 34104 from 1942 to 1946 were as follows:

Year	*Co. 419*	*Co. 421*	*D. 14/34*	*B. 34104*
1942	896	..	..	..
1943	1,827	1,015	..	..
1944	2,937	3,797	1,593	..
1945	3,999	9,275	3,883	950
1946	4,833	12,265	7,114	4,776

The extent of the varietal revolution now taking place in British Guiana, and its rapidity, are shown by these figures, which demonstrate an expansion in acreage under these four varieties from less than 1,000 acres to almost 29,000 acres in 4 years. Present indications from the estates are that this rapid rate of change is being maintained, particularly as regards B. 34104, Co. 421, and D. 14/34, and there is every indication that the acreages under these valuable varieties will be substantially increased in future plantings.

Variety plantings in British Guiana.—The diagram shows the acreages planted in the more important sugar-cane varieties from 1902 to 1946. Particularly between 1910 and 1930 there were considerable areas under mixed varieties—Bourbon mixed with D. 625, and D. 625 mixed with other seedlings—which are not shown. Consequently the total area under cane at any time is not necessarily indicated.

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RECENT DEVELOPMENTS IN SILAGE-MAKING IN DENMARK

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SILAGE was not used to any great extent until the first years after the war of 1914–18. Some beet-tops, together with the sugar-beet pulp, were ensiled in Seeland, Fünen, and Lolland-Falster, the islands where sugar-beet is cultivated, but after 1917 the scarcity of concentrates rich in protein caused an increased interest in silage. Experiments were carried out and R. K. Kristensen [1] reported on the ensiling of some very heterogeneous crops. The original idea was that all kinds of crops might be ensiled, and that certain plants such as maize and sunflower were especially suitable, but under Danish conditions these two crops were found to give a lower yield than beets; in the twenties silage was only of slight importance in Danish agriculture.

When in 1932 the Finnish A.I.V.-method was introduced in Denmark it was especially used for ensiling clover, grass, and lucerne; but not even in the thirties was ensiling at all general. It is, however, clear that the experimental work then carried out, and the experience of the few farmers who then began to make silage, formed a solid basis for the rapid development that ensued in the early forties when the country, on account of the war and the German occupation, was debarred from importing oil-cakes, for in the years immediately before 1940 some 700–800 million kg. a year were imported.

The Statistical Department now undertakes a census of silos [2], which numbered only 1,245 in 1936, but far more in 1943 and 1946 (Table 1).

TABLE 1. *Silos in Denmark, 1943 and 1946*

	1943	*1946*
Number of farms with silos of concrete or wood .	21,632	28,613
Capacity of the above-mentioned silos, cu. m. . .	515,000	698,000
Farms with pit-silos only	25,369	17,823
Total number of farms with silos of any kind . .	47,001	46,436

These figures show that many farms abandoned pit-silos as unsatisfactory in favour of silos made of concrete or wood.

The aggregate number of farms, 46,000–47,000, represents only about 23 per cent. of all farms in Denmark, but as it is mainly the medium-sized and big farms that make silage, these represent a higher percentage of the cultivated area in the country than the 23 per cent. would indicate.

As mentioned, a certain interest in silage was shown on the introduction of the A.I.V.-method, and Table 2 gives the sales of the A.I.V.-acid and formic acid used in subsequent years [3].

TABLE 2. *Sales of A.I.V.- and Formic Acids used in Denmark, 1932–47, for Ensilage*

Year	*A.I.V.-acid (litres)*	*Formic acid (litres)*	*Year*	*A.I.V.-acid (litres)*	*Formic acid (litres)*
1932	6,960	..	1940	1,054,740	..
1933	28,800	..	1941	1,854,540	87,500
1934	61,200	..	1942	1,885,020	398,330
1935	102,540	..	1943	2,170,560	290,000
1936	118,980	..	1944	1,743,000	320,830
1937	135,660	..	1945	1,260,000	..
1938	151,380	..	1946	1,265,000	..
1939	224,400	..	1947	1,369,000	..

Thus during the late war sales multiplied many times.

In 1941 formic acid—under the trade name 'Amasil'—was imported from Germany, and for 4 years its sale was extensive. The decrease in the sale of A.I.V.-acid in 1944–6 was due rather to difficulties in obtaining acid and in packing than to a failing interest; also the scarcity of rubber boots and rubber overalls has of late restricted the use of acid. After Germany's surrender formic acid disappeared from the market, and since then it has not been obtainable in Denmark. As will be shown later, this acid is no match for A.I.V.-acid as a preservative of proteins in the fodder.

To-day mainly beet-tops are ensiled. During the last 10–15 years the cultivation of mangolds has been replaced by that of fodder-beet [4]:

Year	*Area under fodder-beet (ha.)*	*Area under mangolds (ha.)*
1936	24,400	155,200
1946	103,600	69,400

When it is added that the fodder-beet yields about 25 tons of tops per ha., whilst mangolds yield only about 15–20 tons, the reason of this development is clear: a greater yield of beet-tops has provided more ensilage. In the poor districts of Jutland some lupins are ensiled.

Further, practically the whole amount of sugar-beet pulp from the sugar factories, which obtain their production from an area of about 40,000 ha., is ensiled, and in addition a not-inconsiderable quantity of boiled potatoes is ensiled as fodder for pigs.

The beet-tops are most frequently ensiled without addition of acid or other preservatives, but the tops are now crushed to an increasing extent by means of special machines before being filled into the silos; such crushing has proved beneficial to quality, reducing losses both in weight and feeding-value [5].

Experimental Work on the A.I.V.-method

The experiments carried out at the Government Experiment Stations for Plant Culture since 1932 were described by R. K. Kristensen

and Tind Christensen in two official reports [6, 7]. They were designed to ascertain losses and determine the quality of the silage produced.

1933–40. During 1933–40, 15 experiments were carried out in which clover-grass ensiled without any addition and with ½ per cent. molasses was compared with A.I.V.-silage. The percentage losses of dry matter were as follows: without addition, 14·6; with molasses, 20·4; with A.I.V.-acid, 13·9.

Also the following quantities of silage had to be discarded for use as fodder: no addition, 33; with molasses, 12; with A.I.V.-acid, 10 per cent.

Experiments with beet-tops ensiled according to these three methods gave similar results, and a series of experiments in which larger quantities of acid than those prescribed by Virtanen were used showed no smaller losses, even when the amount of acid was increased by 75 per cent., but the fodder became more acid. The protein-loss was not determined in these experiments.

The conclusions drawn from these experiments were, in the authors' words, 'Taken together. the above-mentioned experiments proved that the A.I.V.-process was safest; it gave the lowest loss of dry matter and the least wasted silage; the quality-figures[1] and reaction figures are indicative of a better quality on the whole.'

1941–3. The series of experiments carried out in 1941 to 1943 [7] were even more comprehensive; in addition, loss of dry matter, loss of protein, and formation of ammonia were determined.

For sweet lupins the average percentage losses in 10 experiments were as follows:

	Dry matter	*Crude protein*	*Pure protein*	*Discarded*
With molasses and drainage .	21·1	19·6	46·4	1·8
With molasses, no drainage .	18·4	16·4	44·3	2·4
With A.I.V.-acid and drainage	11·5	14·1	16·5	2·4

The A.I.V.-process gave the best quality; the silage had a pH-value of 3·7, whilst only 3·2 per cent. of the total amount of nitrogen was present in the form of ammonia; in the two processes with molasses the pH-values were 4·6 and 4·4, ammonia amounted to 10·8 per cent. and to 11·1 per cent. of the total nitrogen.

Corresponding, but less comprehensive, experiments with clover-grass showed similar results; the A.I.V.-acid was superior to molasses.

Eleven experiments with beet-tops were carried out on the same plan, and the percentage losses were:

	Dry matter	*Crude protein*	*Pure protein*	*Discarded*
With molasses and drainage .	25·6	21·2	36·6	3·4
With molasses, no drainage .	23·3	22·5	40·5	3·4
With A.I.V.-acid, no drainage	21·5	21·3	24·6	1·9

[1] The quality figures were determined according to a special method introduced by R. K. Kristensen. See *Tidsskrift for Planteavl*, 1923, **29**, 580–1.

Also in these experiments the quality of the silage made with A.I.V.-acid was the best. The pH-values and quantities of ammonia expressed as per cent. of total nitrogen were:

	pH	NH_3–N
Molasses with drainage . . .	4·3	13·3
Molasses without drainage . . .	4·3	11·9
A.I.V.-acid with drainage . . .	4·1	7·9

In 5 experiments with beet-tops comparisons were made between additions of formic acid ('Amasil') and A.I.V.-acid, and a control. The average percentage losses were:

	Dry matter	*Crude protein*	*Pure protein*	*Discarded*
Without addition . . .	35·0	43·1	55·2	5·7
With formic acid . . .	22·0	31·5	40·1	0·8
With A.I.V.-acid . . .	20·0	27·4	22·1	0·0

Again, the A.I.V.-acid showed the best result. The pH-value was 3·8 and NH_3–N only 3·8 per cent. of total N. But the silage with added formic acid was also of good quality, the pH-value being 4·1 and NH_3–N 6·2 per cent. of total N, whilst the silage without addition had pH 4·5 and 12·9 per cent. of NH_3–N.

Almost the same results were obtained by crushing the beet-tops:

	Dry matter	*Crude protein*	*Pure protein*	*Discarded*
Without addition . . .	22·1	28·2	47·5	4·0
With crushing . . .	10·6	16·3	39·5	0·0
With A.I.V.-acid . . .	12·8	20·9	28·3	0·5

Thus the use of A.I.V.-acid proved to be superior to all other methods in reducing loss of pure protein and providing a good-quality fodder.

Immediately after the introduction of the A.I.V.-method in Denmark, the Agricultural Research Laboratory undertook experiments with a view to testing its advantages as compared with hay-making and ensiling with molasses. These experiments, which not only comprised an examination of losses, but also feeding-experiments with milch cows according to the group-method, were reported upon by Olesen, Eskedal, and Østergaard [8], who wrote: 'Hence it seems to be a sound conclusion drawn from this investigation that 5·93 kg. dry matter in A.I.V.-silage has had at least as favourable an influence on the yield as has 6·76 kg. dry matter in hay.'

Digestibility and other trials.—Since then the Research Laboratory has continued the experiments. Numerous group-trials, a series of experiments on digestibility, and several metabolism experiments have been carried out. Møllgaard and Thorbek [9] have described

experiments made to determine the feeding-value of lucerne silage made by the A.I.V.-process.

Experiments made without neutralization of the acid before feeding showed a considerable increase of the thermal energy of the animals. Neutralization of the acid with calcium carbonate reduced to some extent the unfavourable effect, and neutralization with sodium carbonate made it disappear completely; but in the latter case the digestibility of the fodder was reduced, probably owing to the use of too much bicarbonate. The best result was obtained when A.I.V.-lucerne was given together with corresponding or slightly larger quantities of beetroots. The amount of thermal energy was comparatively small in that case, and the digestibility of the fodder was not reduced. The last experiment with lucerne, in which insufficient quantities of acid were used, proved that silage of high pH-value and with a large content of ammonia is not very valuable as a fodder.

A later experiment [10], in which only 6 gm. of bicarbonate per kg. of silage were used (instead of 17 gm.), gave a different result. It was thus possible to compare the digestibility of the fresh lucerne crop with that of the A.I.V.-fodder. In both cases it was found that 71 per cent. of the organic matter was digestible.

The content of sand is often one of the worst disadvantages of beet-top silage; much sand reduces the quality, and in that case A.I.V.-acid had a beneficial effect in that it gave a better digestibility, as the following experiment shows [11].

Two wooden containers were simultaneously filled with sugar-beet tops, one without addition, the other with added A.I.V.-acid. That the tops were rather dirty is shown by the following figures:

	Ash as % of dry matter	*pH of silage*	*Digestibility coefficients*	
			Organic matter	*Crude protein*
Without addition . .	53·0	4·3–5·4	58	54
With A.I.V.-acid . .	48·5	3·7–3·9	64	61

It may be asked how the thousands of farms which make silage by acid are faring. The answer must be that the quality of the silage varies very much, but at any rate it is essentially better than on farms which make silage without the addition of these means or use other means, e.g. molasses, whey, and the like.

Through the good offices of the agricultural societies and the societies of small-holders 2,500 samples of silage were obtained in 1941–3 from hundreds of farms. These samples—accompanied by some information about the kind of crop ensiled and the method applied—were examined for content of dry matter, total N, NH_3–N, ash, and pH-value. In the reports from Jutland H. L. Jensen [12] has given the results of the examination, of which a few details should be mentioned. It was found that a great number of silage samples—even where A.I.V.-acid had been used—were not sufficiently acid, i.e. their pH-values and ammonia-content were too high. But even if the A.I.V.-silage was not very good,

ensiling by other processes was much worse. The beet-top silage from the examinations in 1941 showed the following results:

	NH_3-N (% *of all samples*)	
pH-value	*With A.I.V.-acid*	*Without addition*
..–4·0	20	19
4·0–4·5	47	37
4·5–5·0	24	29
5·0	9	15

and the 1942 examinations gave similar results.

Effect of A.I.V.-silage on milk quality.—Comprehensive investigations carried out by the Federation of Danish Dairy Associations in 1943 gave a similar result; in these it was attempted to combine the examination of the silage with judgement of the quality of milk produced on the farms from which the samples were obtained. The total number of samples was 996 from farms connected with 25 different dairies. All milk producers were offered possibilities for having silage samples tested for the determination of the pH-value, and 4,739 samples were submitted for this test.

The published results [13] indicate a certain correlation between the pH-value of the silage and the quality of the milk produced:

pH-value of silage	*Number of samples*	*Quality of milk, points*
..–3·5	6	11·67
3·5–4·0	133	11·14
4·0–4·5	201	10·83
4·5–5·0	115	10·57
5·0–5·5	62	10·40
5·5	11	10·55

Points were given for smell, taste, and appearance; 11 points indicate very good, 10 points not quite satisfactory.

About two-thirds of the samples derived from the A.I.V.-process were found to be satisfactory; one-third of the samples when formic acid was used; and only one-sixth when no addition was made.

Of the 4,739 samples collected about 2,500 were A.I.V.-samples, and their quality was generally satisfactory. The 700 samples taken from silage made with formic acid had a higher pH but the quality was fairly good. There were 35 silage samples for which whey had been used; the quality of these was generally bad, as were also the 25 samples of silage made with added salt.

It may be said that preservation of feeding-stuffs in Denmark with A.I.V.-acid has proved superior, both in theory and practice, to all other methods; and that under normal feeding conditions with roots as an essential proportion of the fodder, the animals were not injured by the acid.

Thanks to the silage it was possible during the war years to maintain

a considerable production of milk on many Danish farms. This was of great importance particularly to high breeding, as it enabled selection on the basis of the yield of the cows to be continued.

Feeding rations.—Among the herds that have used silage to the greatest extent should be mentioned Stensbygaard, near Stenved. To show how the cattle were fed in the war years, the feeding plan for this farm for 1943–4 is subjoined.

TABLE 3. *Rations for Milch Cows at Stensbygaard*

(Daily ration per cow)

Milk yield in kg. corrected to 4% fat	*Fodder beet (food units)*	*Silage (food units)*	*Mixed concentrates, kg.*	
			I	*II*
0–2·5	3·0	2·0	..	..
2·5–5·0	3·0	3·0	..	..
5·0–7·5	4·0	4·0	..	..
7·5–10·0	4·0	4·0	0·5	..
10·0–12·5	4·5	4·0	1·0	..
12·5–15·0	4·5	4·0	1·5	..
15·0–17·5	5·0	4·0	1·5	0·5
17·5–20·0	5·0	4·0	1·5	1·5
20·0–22·5	5·0	4·0	1·5	2·5
22·5–25·0	5·0	4·0	1·5	4·5
25·0–27·5	5·0	4·0	1·5	5·0
27·5–30·0	5·0	4·0	1·5	7·0

1·1 kg. dry matter in beets and 1·5 kg. dry matter in silage = 1 F.U. = 0·7 starch equivalent.

The mixture of concentrates I contained 30% mustard-seed meal, 30% meat-and-bone meal, 60% bran, malt coombs, &c. Mixture of II contained 20% mustard-seed meal, 15% peas, 65% bran and grain.

The silage consisted chiefly of lucerne and a mixture of clover and grass; all was prepared with A.I.V.-acid.

The herd in question showed the following average yield of 121 cows during the recorded year, Oct. 1, 1943, to Sept. 30, 1944: 4,802 kg. milk; 4·38 per cent. fat; and 210·3 kg. butter-fat [14].

The above was a Danish record for herds of more than 100 cows in the year concerned, but several other breeding herds showed more than 200 kg. butter-fat, thanks to the use of considerable amounts of good silage.

Even if the supply of concentrates had been started immediately after the end of the war, the quantities imported would have been far from sufficient to cover the requirements of Denmark's herds of cows for maximum yield. Partly for this reason and partly owing to the great feeding-value of the beet-tops (which can be preserved in no other way), silage will continue to be of great importance to Danish farming.

Pit-silos and primitive silos of wood will doubtless be gradually replaced by covered concrete silos adjacent to the cowsheds, as this will mean a considerable saving in labour in feeding, whilst the quality of the product will be improved. A.I.V.-acid will surely be used also in the future for crops rich in protein, except beet-tops which are ensiled without acid after crushing in special machines.

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THE BURIED VIABLE-SEED CONTENT OF UPLAND SOILS IN MONTGOMERYSHIRE

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PREVIOUS surveys of hill soils in Mid-Wales to determine their buried viable-seed content [1, 2] have shown that the soils beneath undisturbed natural grassland have contained only the seeds of those grasses and miscellaneous herbs comprising the surface flora. No viable seeds of lowland weeds, and more particularly those associated with arable land, were disclosed in these surveys.

From 1940 to 1943 extensive areas on the hills of Montgomeryshire were reclaimed by ploughing and growing two to three crops of potatoes followed by a ley, or by immediate reseeding. Members of the War Agricultural Executive Committee observed that large patches of typical arable weeds appeared in the new leys following the potatoes. As far as could be ascertained, these hills had never previously been cultivated; only inorganic fertilizers and lime had been used for the arable crops, and the seeds for the leys were of a high grade of purity. It was possible, therefore, that the soils of these particular hills contained seeds of those weed species before the surface vegetation was disturbed. To investigate the problem further, samples of soil were taken in the autumn of 1944 on four of the areas which had been under the Committee's scheme, and on corresponding areas still under natural grassland. The original vegetation and the earlier results of the reclamation work have been described by Ellison [3, 4].

The Hill Areas and the Method of Investigation

The areas sampled in the Welshpool, Newtown, and Llanfyllin districts of the county were as follows:

(*a*) *Heldre Hill, 900–1,000 ft. above sea-level.*—The flora before 1940 was bracken with a fescue-bent sward containing a little Yorkshire fog on the main area, with mat grass (*Nardus stricta*) and heather on the wetter portions. This hill was ploughed in the autumn of 1940, grew potatoes in 1941–3, and was seeded down in 1944; it was during the summer of 1944 that the dense patches of arable weeds appeared.

(*b*) *Esgryn, altitude 1,000–1,100 ft.*—This hill had been a common with three main types of herbage, viz. bracken, with the accompanying grass, heather, and Molinia areas. It was ploughed in 1941, was cropped with potatoes in 1942–3, and was seeded in 1944.

(*c*) *Tynshettin and Brynglas, altitude 900–1,100 ft.*—The original sward at Tynshettin consisted mainly of Molinia but at Brynglas there was considerable variation from mainly bracken to dominant Nardus and Molinia in smaller areas. These areas had pioneer crops of rye and rye-grass in 1943 and were put into seed-mixtures in 1944 with an area of potatoes on Brynglas.

(*d*) *The Kerry Hills, altitude 1,200–1,700 ft.*—Most of these hills consist of a light friable soil with a natural covering of fescue and bent. There are heavier patches where heather and Molinia predominate. The total area of the block taken over by the Committee by the summer of 1944 was 1,030 acres, of which 860 acres had been ploughed and reseeded, most of the mixtures having been sown in the summer of 1943.

The above information is due to Dr. W. Ellison, who also states that the average application of fertilizers was: ground limestone 3 t., 10 per cent. basic slag 10 cwt., ammonium sulphate 2–3 cwt., muriate of potash 2–3 cwt. The Kerry Hill reseeded areas received no potash.

In sampling these hills for buried viable seeds, areas on the improved portions were taken and also on portions which had been left in their natural condition. These separate sampling areas are indicated in the Tables. The Tynshettin areas form an exception in that only reseeded areas were available.

The soil samples were taken to the greenhouses of the Welsh Plant Breeding Station or to a centre at Welshpool and subjected to the usual technique which has been described elsewhere [1]. Seedlings began to appear in Feb. 1945 and counts were continued until end-Dec. 1946, when very few were left. After the first flush of germination in 1945 the soils in the greenhouses were given lime and fertilizers at the same rates as during cultivation and cropping on the hills. The soils were stirred periodically in order to bring all seeds into a favourable position for germination.

Results

The number of seedlings, in millions per acre, derived from buried viable seed down to a depth of 7 in. are given in Table 1 (pp. 166–7), which shows that arable species occurred in all the sampling areas whether these were cultivated and cropped or were permanent hill sward. The centres Heldre and Esgryn provided the greatest contrasts in cultivated *versus* natural lands, many more arable species occurring in the cropped areas A and B than in the permanent sward of Heldre. The cultivated area C had been ploughed only the previous year and thus contrasting with the 4-year-old areas A and B. At Esgryn each of the three cultivated areas also had considerably more arable species than either of the soils beneath the natural swards, and the individual quantities per acre were on the whole greater from the cultivated areas, as at Heldre. All the soils from the Kerry Hills contained small quantities of 6 to 8 arable species, the number in the unploughed being slightly larger than in the cultivated areas. These quantities were of the same density as those from the ploughed and reseeded areas of Tynshettin and Brynglas with the exception of one quantity for *Stellaria media* (chickweed). Seven of the 13 arable species listed in Table 1 gave relatively large quantities of buried viable seed per acre but with considerable variation between different areas. The weed species which had formed the dense patches in the new leys following potatoes were chiefly *Polygonum Persicaria* (pink Persicaria), *Chenopodium album* (fat hen), and

Galeopsis Tetrahit (red hemp-nettle). The soil samples gave very few seedlings of Galeopsis, but Persicaria and *Chenopodium album* were relatively abundant.

It is noteworthy that some of the grassland species mentioned in Table 1 were present in most of the soils and contained large quantities of buried viable seeds. Further, the soils from the wetter areas (the four Tynshettin, the Heldre permanent sward, and the Esgryn Wet, Road, and Rush permanent swards) were all characterized by having relatively large quantities of seeds of species associated with wet soils, namely, *Calluna vulgaris* (common heather), *Erica Tetralix* (cross-leaved heather), Carex species (sedges), the five Juncus (rush) species listed, and certain of the grasses, the two dominant ones, however, being present in all areas. *Ranunculus Flammula* (spearwort) was extremely abundant in the soil of the second area of Tynshettin, and large populations of *Galium palustre* (marsh bedstraw) arose from the soils of the permanent sward at Heldre and the wet soil at Esgryn. Both these soils were of a marsh type, the former surrounding a pond. It was from this soil that by far the largest numbers of *Digitalis purpurea* (foxglove) seedlings originated, and the single instance of a population of *Ranunculus hederaceus* (ivy-leaved crowfoot).

In contrast with these areas was the Esgryn dry area. Although the same in number of species of viable seeds, the quantities are very much smaller than in the adjacent wet area, there being less than half a million Calluna per acre, Erica completely absent, and far smaller amounts of Juncus, especially of *Juncus communis* (common rush) and *J. squarrosus* (heath rush). On the other hand, this dry area had the largest amounts of *Potentilla erecta* (tormentil) and *Festuca ovina* (fine-leaved sheeps' fescue) seedlings of the whole series, and also the largest quantity of *Poa annua* (annual meadow grass) seedlings of its particular group.

The miscellaneous grassland species which arose from the soils of the cultivated and cropped areas were the same as those which came from the permanent grass soils, but among the dominant species the numbers from the cultivated soils are generally much smaller. The seedlings of certain cultivated grasses from these soils originated from the seed-mixtures sown earlier in the year. The same would apply to the *Trifolium repens* (wild white clover) with the exception that it was evidently indigenous in the unploughed Kerry soils. Seedlings of Ulex (gorse) arose from the majority of the soils and plentifully in certain cases, although it was reported [4] that gorse bushes were only occasionally found throughout the areas. The presence of viable *Digitalis purpurea* seeds in the soils of each class of land suggests old woodland on the undisturbed natural grasslands. Their presence in the reclaimed areas may, however, be due to old hedge-banks having been demolished and the material spread over wide sections of soil, although there was no evidence of this at the time of soil-sampling.

Position of seeds in the soil.—When sampling, the top inch beneath the turf was kept separate from the borings taken from that level down to 7 in. This top layer was separately dealt with in the greenhouses and from these data the statement on p. 168 was prepared for a reseeded area

TABLE 1. *Number of Viable Seeds of each Species in Millions per Acre to a Depth of 7 Inches*

	Tynshettin				Heldre				Esgryn							Kerry Hills					
	Reseeded areas				Potatoes and then reseeded		Re-seeded	Natural sward	Potatoes and then reseeded			Natural swards				Reseeded			Natural swards		
	1	2	3	4	A	B	C		1	2	3	Wet	Dry	Road	Rush	1	2	3	1	2	3
Arable species:																					
Anagallis arvensis Linn.	..	..	..	..	0·04	..	..	..	0·04	..	0·04	..	..	..	..	..	..	..	..	..	..
Anthemis Cotula Linn.	..	..	..	..	0·10	..	..	..	..	..	0·04	..	..	..	..	..	..	..	..	..	..
Chenopodium album Linn.	0·10	0·10	0·10	..	2·63	0·57	..	..	1·14	0·07	1·71	0·20	..	..	..	..	0·07	..	..	..	..
Galeopsis Tetrahit Linn.	..	..	..	..	0·01	..	..	..	0·04	..	..	..	..	..	..	..	..	..	..	..	..
Gnaphalium uliginosum Linn.	..	..	0·20	..	0·02	0·20	..	0·10	4·77	0·27	1·23	0·27	0·20	..	..	..	0·14	..	..	0·07	..
Polygonum aviculare Linn.	0·10	..	..	..	0·51	0·02	..	..	..	..	..	..	..	..	..	0·14	..	..	0·07	0·07	..
Polygonum Convolvulus Linn.	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Polygonum Persicaria Linn.	0·10	1·33	0·51	0·51	11·00	0·45	0·31	0·41	0·90	1·22	0·61	..	..	..	0·82	0·34	0·14	0·07	0·34	1·43	0·82
Senecio vulgaris Linn.	0·10	0·10	0·31	..	0·43	..	..	0·30	13·76	12·75	5·52	..	0·41	0·20	0·42	0·14	0·14	..	..	..	0·61
Silene Cucubalus Wibel	..	0·10	0·31	..	0·02	0·04	0·20	0·10	..	..	0·12	..	..	..	0·20	..	..	..	0·14	..	..
Sonchus oleraceus Linn.	0·10	..	..	0·20	0·06	0·02	..	..	0·04	..	0·04	..	..	..	..	..	..	..	..	..	..
Spergula arvensis Linn.	..	..	..	0·10	0·02	0·04	..	0·20	0·12	1·36	0·90	..	..	..	..	..	..	..	..	..	..
Stellaria media Vill.	0·51	0·20	5·40	..	2·02	0·57	..	..	16·52	19·30	4·70	0·41	1·22	0·20	0·20	0·07	0·34	0·07	4·28	0·41	0·54
Grassland and other miscellaneous species:																					
Agrimonia Eupatoria Linn.	..	..	..	0·10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Anagallis tenella Linn.	..	..	..	..	..	..	..	0·10	..	..	..	..	..	..	..	..	..	..	..	..	..
Calluna vulgaris Salisb.	3·47	..	..	..	1·63	2·33	0·10	4·18	0·04	0·27	3·10	11·00	0·41	..	13·03	..	0·14	..	0·27	..	0·14
Cardamine hirsuta Linn.	1·02	7·03	0·41	0·41	0·45	0·41	..	..	..	0·07	0·25	..	..	0·20	..	..	0·07	..	0·48	0·07	0·27
Cardus palustris Linn.	..	..	..	0·10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Carex spp.	0·61	6·94	1·63	0·92	0·78	0·53	0·10	1·84	0·29	0·61	0·70	2·04	..	0·61	..	0·07	0·07	0·22	0·41	0·34	0·14
Centaurea nigra Linn.	..	..	..	..	..	..	..	..	0·04	..	..	..	0·20	..	..	..	..	..	..	..	..
Cerastium vulgatum Linn.	0·10	0·20	0·31	3·37	0·12	0·04	..	..	0·29	0·07	..	..	..	..	..	..	..	..	..	..	0·14
Digitalis purpurea Linn.	..	..	0·92	..	0·82	0·12	2·90	26·11	..	..	..	0·20	..	0·20	..	0·22	..	..	4·42	0·07	..
Epilobium tetragonum Linn	0·10	0·20	0·10	..	0·10	0·10	..	..	0·08	..	0·08	..	..	..	..	0·07	..	0·27	..	..	0·07
Erica Tetralix Linn.	5·72	..	..	..	..	0·26	..	..	0·12	0·48	0·74	5·52	..	..	5·71	..	..	..	..	..	..
Galium saxatile Linn.	..	..	..	0·20	0·35	0·33	0·31	7·54*	0·12	0·22	0·53	3·87*	1·22	0·41	..	..	0·34	..	0·61	1·83	0·22
Heracleum Sphondylium Linn.	..	..	..	..	0·04	0·02	..	..	0·04	..	..	..	..	..	..	..	..	..	..	..	..
Hydrocotyle vulgaris Linn.	..	0·20	..	..	..	..	..	..	..	..	0·04	..	..	..	..	..	..	..	..	..	..
Hypericum humifusum Linn.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·07	..
Hypochoeris radicata Linn.	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Juncus articulatus Linn.	0·31	2·45	0·92	1·22	0·04	0·04	..	2·85	0·04	0·07	0·12	..	..	0·41	0·61	..	..	..	..	..	..
Juncus bufonius Linn.	21·70	90·70	42·30	55·50	1·32	0·94	0·31	32·13	2·04	0·95	1·92	1·02	0·20	4·28	6·93	..	0·07	0·22	0·07	0·14	2·86
Juncus bulbosus Linn.	0·10	..	..	..	0·06	..	..	1·93	..	..	..	..	..	..	2·04	..	..	..	..	..	..
Juncus communis Mey.	11·32	60·25	43·50	50·40	3·23	2·61	1·12	21·10	3·88	6·40	6·84	10·80	3·46	4·70	12·43	1·36	1·57	0·82	1·97	1·49	1·43
Juncus squarrosus Linn.	14·20	5·50	3·86	0·82	1·41	1·66	0·20	5·81	3·79	8·49	9·61	50·20	1·22	1·22	12·43	0·22	0·22	0·34	..	0·07	0·61
Luzula campestris DC.	0·20	..	0·10	..	..	0·04	..	0·41	..	0·07	0·04	..	0·20	..	..	..	..	..	0·34	0·27	..
Myosotis arvensis Hill	..	..	..	..	..	0·06	..	..	..	..	..	..	0·20	..	..	..	..	..	..	..	..
Ononis arvensis Linn.	..	..	..	..	0·02	0·04	..	..	..	..	..	..	..	0·20	..	..	..	..	..	..	..
Oxalis Acetosella Linn.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·22	..
Plantago major Linn.	0·10	..	0·20	0·10	0·04	..	..	..	..	0·07	..	..	..	..	..	0·07	0·14	..	0·14	..	..
Potentilla erecta Hampe.	0·31	1·94	1·12	1·12	0·14	0·02	1·73	0·20	0·75	0·07	0·08	0·61	4·48	4·08	..	0·07	0·14	..	0·22	0·22	0·07
Primula veris Linn.	..	..	..	..	0·29	..	..	..	..	..	..	..	..	0·61	..	..	..	..	..	0·07	..
Ranunculus Flammula Linn.	0·10	22·60	2·24	0·10	0·06	0·02	..	0·61	..	..	..	..	..	..	..	..	..	..	..	..	..
Ranunculus hederaceus Linn.	..	..	..	..	..	..	..	5·71	..	..	..	..	0·20	0·20	..	0·27	..	..	0·54	..	..
					0·10	0·02	0·10	0·61												0·07	0·07

Ranunculus hederaceus Linn.	..	..	..	..	..	..	..	5·71	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Ranunculus repens Linn.	0·20	4·29	2·04	0·31	0·10	0·02	0·10	0·61	..	..	..	..	0·20	0·20	..	0·27	..	..	0·54	..	..	..
Rubus fruticosus Linn.	..	..	..	..	0·06	0·02	..	..	..	0·14	..	..	..	..	..	..	..	..	..	0·07	0·07	..
Rumex Acetosa Linn.	..	..	0·72	..	..	0·02	..	..	0·04	..	..	..	..	..	..	..	..	..	..	..	..	..
Rumex Acetosella Linn.	..	0·31	1·33	..	0·33	0·10	0·10	1·43	0·82	0·22	0·16	..	..	..	..	0·07	0·22	..	0·27	0·14	1·57	..
Rumex obtusifolius Linn.	0·31	..	..	..	0·02	0·02	..	..	0·04	..	..	0·20	..	..	..	..	..	..	..	..	..	..
Sagina procumbens Linn.	3·78	2·86	2·35	15·70	0·39	0·08	..	0·20	0·16	0·07	0·08	..	0·20	0·20	0·20	0·22	0·07	0·07	0·34	..	1·70	..
Scirpus setaceus Linn.	..	..	..	..	0·02	..	..	0·41	0·04	0·27	0·27	0·82	..	..	0·41	..	..	..	..	0·07	..	..
Senecio viscosus Linn.	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Taraxacum officinale Weber	..	..	0·10	1·22	0·02	0·04	0·20	0·10	0·08	0·34	0·16	..	..	0·20	..	..	0·27	..	0·14	..	..	..
Ulex europaeus Linn.	0·10	..	0·10	..	0·43	0·24	..	0·51	0·12	0·14	0·08	2·04	0·82	0·61	0·20	0·27	0·07	0·14	1·97	1·36	..	..
Urtica dioica Linn.	..	0·10	0·10	..	..	0·20	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Veronica officinalis Linn.	..	..	..	0·10	0·06	..	..	..	..	..	..	..	..	0·20	..	..	..	..	0·07	..	0·14	..
Veronica serpyllifolia Linn.	..	..	..	0·41	0·02	..	..	..	..	..	..	..	..	0·20	..	..	..	..	0·14	..	..	..
Viola canina Linn.	0·51	0·61	0·31	0·31	0·04	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Viola lutea Huds.	0·10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Grasses:																						
Anthoxanthum odoratum Linn.	..	0·10	..	0·10	..	0·06	..	0·10	..	..	0·04	..	..	..	..	..	0·14	..	..	..	0·07	
Agrostis spp.	23·60	14·64	17·80	22·40	4·31	5·20	4·00	31·21	3·35	2·79	4·08	14·30	7·95	21·22	2·65	0·68	2·45	1·22	2·38	1·49	6·86	
Bromus mollis Linn.	..	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Dactylis glomerata Linn.	..	..	..	..	0·02	0·08	..	..	..	..	..	..	0·41	..	..	..	0·07	0·07	0·07	..	..	
Deschampsia caespitosa Beauv.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·07	..	0·54	0·07	0·14	..	
Deschampsia flexuosa Beauv.	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Festuca rubra Linn.	..	..	..	..	0·27	0·24	..	1·22	0·45	0·22	0·29	0·61	1·63†	0·61†	..	0·22	0·07	0·68	0·48	0·34	0·27	
Holcus lanatus Linn.	0·61	1·63	0·51	14·00	0·06	0·04	0·10	0·10	..	..	0·04	..	..	..	..	..	0·07	..	..	0·07	..	
Lolium italicum Braun	..	..	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Lolium perenne Linn.	..	0·10	..	..	0·10	0·02	..	..	..	0·34	0·20	..	..	..	0·20	..	..	..	..	..	..	
Molinia caerulea Moench	..	..	0·10	..	..	..	..	0·10	0·04	..	..	..	..	..	..	..	..	..	..	..	..	
Phleum pratense Linn.	1·33	0·41	1·33	0·31	..	..	..	..	0·04	0·14	0·08	..	..	..	0·41	..	..	0·07	..	..	..	
Poa annua Linn.	6·93	3·47	1·84	5·60	0·65	0·33	0·61	0·82	9·26	2·86	2·25	0·82	3·87	1·02	0·82	0·68	0·14	0·75	0·95	0·48	7·75	
Poa pratensis Linn.	0·10	..	..	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	0·41	..	
Poa trivialis Linn.	0·10	0·31	..	0·51	0·12	0·16	0·10	..	0·98	..	0·08	..	..	..	..	..	..	0·07	0·27	..	0·14	
Sieglingia decumbens Bernh.	..	0·41	0·10	0·10	0·04	0·02	..	..	0·04	..	0·04	..	..	..	..	..	..	..	..	..	..	
Legumes:																						
Lotus corniculatus Linn.	..	..	..	0·10	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Trifolium minus Sm.	..	..	..	0·10	..	0·02	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	
Trifolium pratense Linn.	..	..	..	..	0·04	0·06	..	..	..	..	..	..	..	..	..	..	..	..	..	0·07	..	
Trifolium repens Linn.	0·41	0·61	2·14	1·02	0·18	0·16	..	..	0·33	0·54	0·41	0·20	..	..	..	0·07	0·07	0·07	0·14	0·07	0·07	

* Seedlings of *Galium palustre* Linn. in these areas.
† Seedlings of *Festuca ovina* Linn. in these areas and also the Kerry Hill areas.

at Tynshettin, and the potato and then reseeded areas at Heldre and Esgryn:

Percentage of viable seeds of miscellaneous species in the top inch of soil of:

	(*a*) *Arable species*		(*b*) *Grassland species*	
	Total no. of seeds to depth of 7 in.	*Per cent. in top inch*	*Total no. of seeds to depth of 7 in.*	*Per cent. in top inch*
Tynshettin III .	64	61	1,025	18
Heldre A . .	828	34	599	37
Heldre B . .	92	39	496	32
Esgryn I . .	913	73	303	13
Esgryn II .	514	86	279	19
Esgryn III .	375	57	601	12

The numbers of seeds of arable species which occurred in the soils of these six areas are large enough to provide some indication of their significance. The numbers for these species were too small in the remaining areas to give any definite comparable data.

In the Heldre areas the percentages of arable seeds and of grassland seeds in the top inch were fairly similar. In the Tynshettin and the three Esgryn centres, however, there were far greater proportions of the arable seeds near the surface than in the corresponding populations of typical grassland species. As only miscellaneous species have been compared in each group and therefore represent the same type of seed, there is definite reason to believe that the arable weed-seed population of these soils has been derived from the surface at a recent date.

The remaining proportions of those seeds shown in the above statement occurred in the soil layer between 2 and 7 in. from the surface. To investigate the content of buried viable seed in a lower soil level, second borings were taken from the base of the first borings on four areas on Heldre and four areas on Esgryn. These data are included in Table 2, which gives the populations at from 7 to 12–14 in. from the surface.

The data show that seeds of arable species occurred at this lower level in 7 of the 8 areas sampled in this manner, but that the number of species did not exceed 3 in any one area, and the populations were small except for a single instance in the Esgryn cultivated area. Most noteworthy are the small number of species of all kinds, and the relatively low populations throughout, as compared with the data for the upper 7-in. layer (Table 1). The latter factor is particularly noticeable in the Juncus species and Agrostis species (bent) and *Poa annua*, although the seeds of these plants have occurred in practically every area sampled at this lower level, as was the case at the upper level. In 14 instances buried viable seeds of a species have occurred in an area, the same species not occurring in the same area for the upper soil layer as recorded in Table 1. Persicaria in 2 areas, and each of the other 4 arable weeds in a single area are cases in point. That seed-populations diminish with increasing depth in soils beneath grassland has been shown by Chippendale and Milton [5] in an earlier investigation.

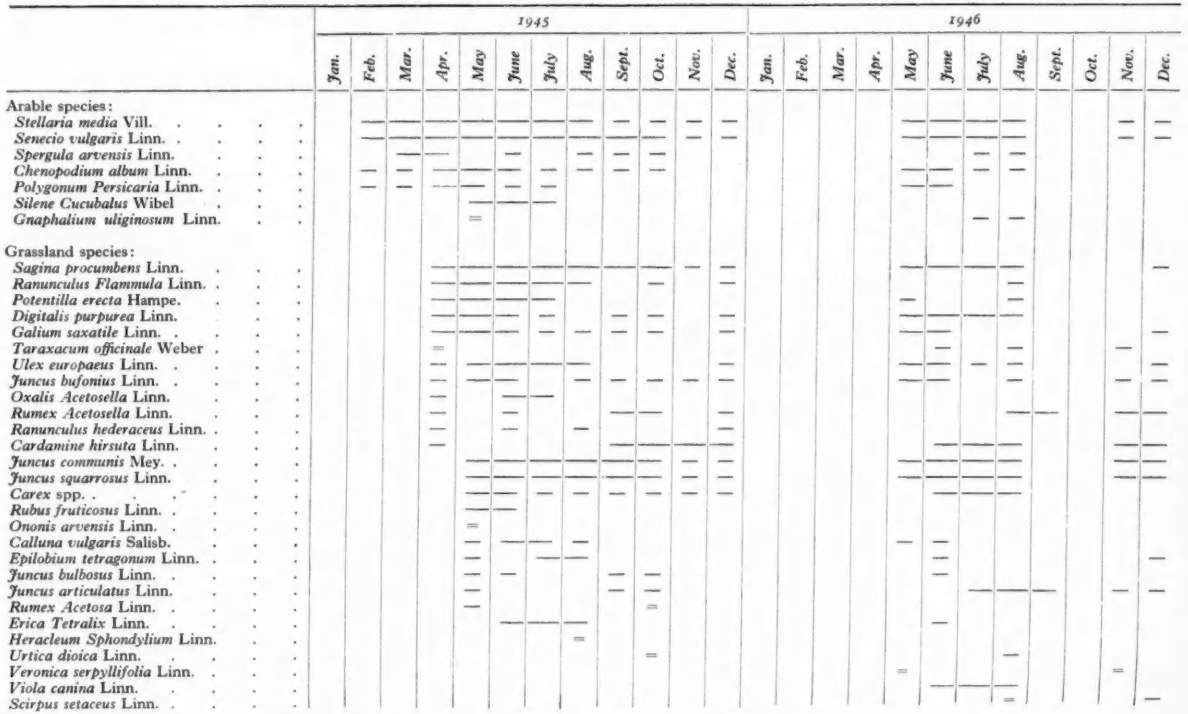
Periodicity of germination.—Soil samples from all the areas were put out in the greenhouses in Nov. 1944 and the dates at which the seedlings derived from the buried seeds appeared were recorded throughout the 2 years of the trial. The data are given in Table 3 in terms of the chief, and also the minor, germinating periods for those species in which the seedlings were numerous enough to provide results.

TABLE 2. *Number of Viable Seeds of each Species in Millions per Acre in the Lower Soil Level (7 to 12–14 inches)*

	Heldre				*Esgryn*			
	Cropped		*Reseeded C*	*Natural sward*	*Cropped*	*Natural swards*		
	A	*B*				*Wet*	*Dry*	*Road*
Arable species:								
Polygonum Persicaria Linn.	..	..	..	..	..	0·41	..	0·41
Senecio vulgaris Linn.	0·20	..	..	..	3·67	0·20	0·41	0·20
Silene Cucubalus Wibel	..	..	..	..	..	0·20	..	..
Sonchus oleraceus Linn.	..	..	..	..	..	..	0·20	..
Stellaria media Vill.	..	0·41	0·41	..	0·82	..	..	0·20
Grassland species:								
Anagallis tenella Linn.	..	0·20	..	..	..	..	..	..
Calluna vulgaris Salisb.	..	..	..	3·06	..	..	..	..
Cardamine hirsuta Linn.	0·41	..	..	..	..	..	0·61	0·10
Carex spp.	..	..	..	1·22	0·20	..	..	0·41
Digitalis purpurea Linn.	..	..	..	0·41	..	..	..	..
Erica Tetralix Linn.	..	..	..	..	..	..	..	1·22
Galium saxatile Linn.	..	0·61	..	1·43	..	0·20	..	..
Juncus articulatus Linn.	..	0·20	..	0·20	0·20	..	..	0·20
Juncus bufonius Linn.	..	0·20	0·20	12·00	0·41	0·20	..	0·20
Juncus communis Mey.	..	1·22	0·61	4·48	1·22	0·61	1·84	3·06
Juncus squarrosus Linn.	..	..	0·20	0·41	0·41	2·65	0·20	2·24
Potentilla erecta Hampe.	..	..	..	..	..	..	1·02	0·61
Rumex Acetosella Linn.	..	0·20	0·41	..	0·20	..	..	..
Sagina procumbens Linn.	..	..	..	..	0·20	..	9·40	1·43
Ulex europaeus Linn.	0·41	..	..	0·61	..	..	0·20	..
Grasses:								
Agrostis spp.	0·20	2·65	1·22	3·46	1·84	1·63	1·22	2·44
Bromus mollis Linn.	..	..	..	..	..	..	..	0·20
Festuca rubra Linn.	0·20	0·41	..	..	0·20	..	..	..
Phleum pratense Linn.	..	0·20	..	..	..	0·20	..	..
Poa annua Linn.	0·41	..	0·20	0·61	0·82	..	0·20	1·02
Poa trivialis Linn.	..	..	..	..	0·20	..	..	..
Legumes:								
Trifolium repens Linn.	0·41	..	..	..	..	..	0·20	0·41

Seedlings of arable species were the first to appear, four in February and a fifth in March. Four grass species and wild white clover also started in March. In April and May most of the miscellaneous grassland species, two more arable species, and the remainder of the grasses began germinating except *Molinia caerulea* (flying bent). Later germinations were: *Erica Tetralix* in June, Molinia in July, *Heracleum Sphondylium* (hog-weed) in August, and *Urtica dioica* (nettle) in October. Delayed germination of a still more definite type was shown by *Veronica serpyllifolia* (thyme-leaved speedwell), *Viola canina* (dog violet), and *Scirpus setaceus* (bristle scirpus), which did not start until May, June, and August of the second year. Practically all the species had a chief germinating period in the first year, whilst 5 of the 7 arable species in the Table, 14 miscellaneous grassland species, and 3 grasses had chief

TABLE 3. *The Chief Germinating Periods (marked with a continuous line) and the Minor Germinating Periods (marked with a dash) of Certain Species during the Experiment*



= signifies a chief germinating period.

periods in the second year also. It is noticeable that in this second year there was a distinct grouping of germinations from, approximately, May to August, and again from November into December, and further, that in every case when a species had given germinations at the end of this second year, germinations had previously taken place in the earlier period of the same year.

Discussion

With regard to the incidence of the viable seeds of arable weeds in these hill soils (which were beneath natural grasslands until reclamation began in 1940), the most striking fact is that their seeds occurred to a greater or lesser degree throughout all the areas, whether cropped with potatoes and then seeded down, whether immediately reseeded, or whether still in natural sward. It is significant, however, that the areas on Heldre and Esgryn which had been arable-cropped had far greater numbers of arable weed-seeds in their soils than the other areas. It was, moreover, on these areas that the dense patches of weeds arose in the ley following the potatoes. Although only lime, artificial fertilizers, and seed-mixtures free from weed-seeds had been used, the results clearly indicate that the main contamination with arable weed-seeds took place during the three croppings with potatoes. This is readily understood from Salisbury's work on the great reproductive capacity of plants [6], even if only an occasional arable weed is allowed to become established and to ripen and shed its seed. Thus he gives 720 seeds as the reproductive capacity of a single plant of hemp-nettle, taking into account the average seed-output per plant and the percentage germination. *Senecio vulgaris* (groundsel) is given as 1,000, whilst the average seed output per plant of other species here dealt with is in some cases many thousands. Stapledon [7] has indicated that a root-crop provides very favourable spreading conditions for weeds owing to the rich soil and bare ground. Since certain numbers of arable weed-seeds were present in our undisturbed areas, it can be assumed that they were not introduced into the cropped areas during cultivation and the growing of potatoes, but that these conditions provided the opportunity for these seeds already present to germinate and become established and ultimately to reproduce. Prior to 1940, these areas would have had presumably a similar buried viable-seed content to the eight unploughed sections of the hills as given in Table 1, i.e., relatively large numbers of miscellaneous grassland species together with a few arable species.

The means by which seeds could have been carried to these upland areas are (*a*) the carting of stock-yard refuse on to a hill grassland where any seeds it contained could not contaminate the farm fields; (*b*) sheaves of corn containing weed-seeds might have been carted out for stock-feeding on the open hill; and (*c*) farm-stock going up on to the hills from the lowland fields may have distributed seeds which had passed through the body and yet retained their viability. Dore and Raymond [8] have shown that the number of seeds that are able to withstand animal digestion and are distributed in the manure can be considerable at certain times of the year. In the present experiment there is no doubt

that the viable seeds of wild white clover beneath the unploughed Kerry Hill areas originated mainly in the last-named way. It is also possible that in certain hill districts land which was believed never to have been ploughed was found upon ploughing to have lime-lines at plough depth, showing that cultivation had been carried out at some earlier period. No observations of this factor have been recorded in the present instance, but if there were any earlier cultivations they were probably carried out at least 50 years earlier than the reclamation scheme, for the lands had passed to the last retrograde stage of Molinia, Nardus, and Juncus species.

With regard to the age of seeds in the soil, the experiment of Beal, as reported by Darlington [9, 10], has shown that seeds can retain their viability in the soil up to 50 or even 60 years. Also the experiment begun by Duvel, the results of which have been given by Goss [11], shows that the seeds of numerous species grew after being buried for 20 years in soil. Crocker [12] commenting on these experiments mentions that size of seed and depth of burial have no effect upon life-span of seeds, and also that many seeds without hard coats are also long-lived; hence it is probable that many retain their viability much longer in the soil than in dry-storage in the air. The present experiment indicates that the areas under permanent sward where the soils were wet had larger populations than an area with much dryer soil. This finding occurred in the first investigation of this nature conducted at Aberystwyth [5], and again in a buried viable-seed survey of hill lands [1]. Ford Prince and Hodgdon [13] have also found a significant difference in the numbers of viable seed in light and heavy soils, amounting to 30 per cent. more viable seed in soils of the heavy group, whilst Chepil [14] found a higher emergence of seedlings derived from seeds buried in calcareous clay soils than in loam or sandy loam soils.

Concerning the length of life of seeds in the soils beneath swards of widely different ages, the experiment referred to [5] showed that whereas arable seeds diminish in numbers with the increasing age of the pasture, the evidence suggested that these seeds can retain their viability in the soil for possibly as long as 70 years. Length of life of buried seeds has also been enumerated in the results of Oosting and Humphreys [15], who state that the germination of seeds of several species from habitats in which the parent plants do not grow indicates the possibility that under natural conditions seeds may lie buried for long periods and retain their viability.

Since weed-seeds of arable species were also found in the layer of soil from 7 to 12 or 14 in. below the surface and in some areas were not recorded in the 1–7-in. layer, it can be concluded that a very slow contamination of the soils of these hills over a long period was due to the movements and the feeding of farm animals, the seeds being carried to the lower levels by various natural agents. The result has been not only an addition of arable weed-seeds to the populations of seeds derived from the native grassland species, but also small amounts of wild white clover and of the grasses associated with cultivated swards. When these formerly undisturbed areas were at last ploughed, the viable arable seeds

in particular were enabled to become plants that under root-crop conditions produced an abundance of ripe seed, which in turn became buried. The data have shown that the bulk of this shed seed remained in the top few inches of soil following the cultivation required for the seeding-down of the areas. That the growing of root-crops enabled this multiplication of weed-seeds to take place is conclusively shown in the contrast between these areas and those which were ploughed and immediately reseeded, the buried-seed numbers for areas A and B of Heldre compared to area C being the most striking instance.

The observation that seeds of arable species were the first to germinate agrees with a similar earlier finding [5]. In Table 3 a sub-group is discernible in which among those species which commence germinating in a particular month, there are some which begin a chief germinating period from that date, whilst others germinate to a relatively slight extent and have their maximum periods later in the year. Others again have a chief period in one particular month and do not germinate again until the following year when their germinations have a wider range, as in the cases of *Gnaphalium uliginosum* (cudweed) and *Taraxacum officinale* (dandelion), whilst others of this type do not germinate after the first year, *Ononis arvensis* (rest-harrow) among the herbs and Molinia among the grasses being examples. Almost every species has its own characteristic behaviour, but similarities do exist, as between *Stellaria media* and *Senecio vulgaris*, both in the first- and second-year germinations; and also between *Juncus communis* and *J. squarrosus* and between Agrostis and *Poa annua*. It is noticeable that *Juncus bulbosus* (bulbosus rush) and *J. articulatus* (jointed rush) behaved quite differently from the two former Juncus species, especially in the first-year germinations.

The factor of delayed germination was apparent among those species which did not germinate until the late summer of the first year and, more especially, not until the second year. Brenchley and Warington [16] mention that many seeds in the soil have a period of natural dormancy during which they will not start growth even if placed in conditions favourable for germination, the length of the period varying with the species. Brenchley [17] also found that most species showed a definite periodicity of germination under conditions of continuous corn-growing, comparatively few species germinating freely throughout the year. In a further publication [18] these two investigators give data on prolonged natural dormancy of certain species ranging from 4 to 10 years and state that species which produce many seeds which remain naturally dormant over long periods form an incalculable element in the weed flora. In discussing the influences affecting the germination of weed-seeds in soil, Warington [19] states that periodicity in the germination of certain weed-seeds is probably linked up with various internal and external conditions, among which temperature at any stage of the life-history of the seed presumably plays an important part. Bibbey [20] conducted experiments which showed that aeration of the soil by tillage encouraged the germination of dormant seeds, whilst Hanf [21] considers that a single factor is seldom responsible for germination, but that a combination of all the environmental conditions promotes or inhibits development. In

regard to periodicity of individual species, Chepil [22] states that most species contain some seeds that germinate immediately after they are placed under favourable conditions, but that a proportion of the remaining seeds lie dormant for various periods. He has recorded the relationship between the periodicity of germination and the relative seriousness of a weed in numerous individual cases. Data from the present experiment did not extend beyond 2 years, but even so, this factor of delayed germination was operative. A comparison made with other data recorded over a similar period of years [23], but in which the soils were put out in the greenhouses at the end of April instead of in November as in the present instance, shows that although the differential germination among the species in the early part of the first year is hidden by not putting any existing buried viable seeds into a favourable germinating position until late spring, delayed germination into the following year was nevertheless shown by certain species.

The information provided by this survey justifies a surmise as to what would be the surface vegetation of these reclaimed areas if they were allowed to revert from their present condition. It has been shown that the buried seeds of Agrostis are prolific and that the seeds of *Trifolium repens* are plentiful in most of the soils examined. There is no doubt, in the light of previous work of this nature in Cardiganshire [1], that as the cultivated grasses in the new leys die out Agrostis will take their place and, provided that the grazing management remains efficient, *Trifolium repens* will be a companion plant to the Agrostis, its source being partly existing plants and partly buried viable seeds which are brought by any agency, such as stock-treading, near enough to the surface for germination. Ford Prince and Hodgdon [13] state that in all the soils they tested these two species occurred in sufficient quantity eventually to produce a mixed sward if fertility conditions and other plant control were correct. On less fertile areas of the hills in question there is likely to be a reversion to *Galium saxatile* (heath-bed straw) and *Potentilla erecta* and *Ulex europaeus* (gorse) on the dryer areas, mixed with the Agrostis and Festuca, judging by the quantities of their buried viable seeds. The wetter areas of the hills will undoubtedly revert quickly to Juncus species and, in view of previous observations, especially to *Juncus communis*, whilst Carex species, *Calluna vulgaris*, and *Erica Tetralix* will be associated plants. The reappearance of *Molinia caerulea* and *Nardus stricta* (moor mat grass) derived from their buried viable seed are problematical, for few seedlings of the former species in relation to the surface vegetation have arisen from these soils, and no seedlings of the latter species. Again, in view of similar findings and the subsequent changes in the flora of hill areas it is probable that these two grasses would not become dominant in the surface vegetation for a long time, even on those areas which could be classed as Molinia with Nardus prior to the reclamation scheme. That floristic changes have already begun is mentioned by Ellison [24], who gives the stock-carrying capacities of these reclaimed upland areas for the grazing periods 1945 and 1946. If the stocking of these hills is maintained in the degree described, the beneficial effects on the better grasses and wild white clover should prevent any rapid reversion, except

on areas where the soil becomes waterlogged, thus allowing the Juncus species to become established and to compete with the existing herbage.

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APPENDIX

Common names of the following species not given in the text:

Anagallis arvensis Linn. Scarlet pimpernel.
Anagallis tenella Linn. Bog pimpernel.
Anthemis Cotula Mey. Mayweed.
Agrimonia Eupatoria Linn. Agrimony.
Calluna vulgaris Salisb. Heather.
Cardamine hirsuta Linn. Bitter cress.
Carduus palustris Linn. Marsh thistle.
Centaurea nigra Linn. Knapweed.
Cerastium vulgatum Linn. Mouse-ear chickweed.
Epilobium palustre Linn. Marsh willow herb.
Hydrocotyle vulgaris Linn. Marsh pennywort.
Hypericum humifusum Linn. Trailing St. John's wort.
Hypochoeris radicata Linn. Cat's-ear.
Juncus bufonius Linn. Toad rush.
Luzula campestris DC. Field woodrush.
Myosotis arvensis Hill. Forget-me-not.
Oxalis Acetosella Linn. Wood-sorrel.
Plantago major Linn. Broad-leaved plantain.
Polygonum aviculare Linn. Knot grass.
Polygonum Convolvulus Linn. Bind weed.
Potentilla erecta Hampe. Tormentil.
Primula veris Linn. Cowslip.
Ranunculus repens Linn. Creeping buttercup.
Rubus fruticosus Linn. Bramble.
Rumex Acetosa Linn. Sorrel.
Rumex Acetosella Linn. Sheep's sorrel.
Rumex obtusifolius Linn. Broad-leaved dock.
Sagina procumbens Linn. Pearlwort.
Senecio viscosus Linn. Viscosus senecio.
Silene Cucubalus Wibel. Bladder campion.
Sonchus oleraceus Linn. Sow-thistle.
Spergula arvensis Linn. Corn spurrey.
Veronica officinalis Linn. Common speedwell.
Viola lutea Huds. Mountain pansy.
Anthoxanthum odoratum Linn. Sweet vernal grass.
Bromus mollis Linn. Soft brome.
Dactylis glomerata Linn. Cocksfoot.
Deschampsia caespitosa Beauv. Tussock grass.
Deschampsia flexuosa Beauv. Wavy hair-grass.
Festuca rubra Linn. Fine-leaved red fescue.
Lolium italicum Braun. Italian ryegrass.
Lolium perenne Linn. Perennial ryegrass.
Phleum pratense Linn. Timothy grass.
Poa pratensis Linn. Smooth-stalked meadow grass.
Poa trivialis Linn. Rough-stalked meadow grass.
Sieglingia decumbens Bernh. Heath grass.
Lotus corniculatus Linn. Birdsfoot trefoil.
Trifolium minus Sm. Yellow suckling clover.
Trifolium pratense Linn. Red clover.

ECONOMIC ASPECTS OF THE COTTON INDUSTRY OF NORTHERN NIGERIA

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Introductory.—Nigeria produces less than 0·2 per cent. of the world's cotton, but among Empire producers it takes fourth or fifth place [1]. Three-quarters of its production is classed on the English market as Good Middling or Strict Good Middling, and it is valued at about 40 points more than American Middling. The staple-length varies between 1 and 1⅛ in.

In the years before 1939, cotton seed and lint ranked seventh among Nigeria's exports. Table 1 shows the quantity and value of lint and seed

TABLE 1. *Exports of Cotton Lint and Seed for 10-year Periods since 1910*

Period		*Year*	*Lint cwt.*	*Value £*	*Seed tons*	*Value £*	*Combined total value £*
1910–19 .	Average	..	39,960	167,514	2,418	10,918	178,432
	Highest	1916	66,555	243,949	864*	2,526	246,475
	Lowest	1918	13,214	97,399	405	15,412	112,811
1920–9 .	Average	..	99,782	571,873	6,698	42,207	614,080
	Highest	1926	179,315	1,182,050	11,697	62,742	1,244,792
	Lowest	1922	58,942	271,087	2,409	10,408	281,495
1930–9 .	Average	..	129,253	338,670	8,341	49,504	388,174
	Highest	1936	222,193	553,581	16,308	90,887	644,468
	Lowest	1932	23,818	51,463	533	1,605	53,068
1940–5 .	Average	..	168,745	522,086	4,232	12,299	534,385
(6 years)	Highest	1942	370,346	1,126,709	5,635	9,524	1,136,233
	Lowest	1945	21,199	63,601	2,045	4,375	67,976

* Highest seed export was 5,887 tons in 1913 valued at £14,431.

exported, expressed as the average of 10-year periods since 1910 [2]. The amounts exported varied considerably from year to year, and the range of fluctuation is shown by quoting the progress for the years of highest and lowest export. Table 2 shows the countries to which Nigerian cotton lint was exported in 1935 and 1938.

Seventy-five per cent. of the cotton exported during the 15 years before the Second World War was grown in the Northern Provinces (the remainder in the Southern (Western) Provinces). The producing area lies roughly between latitudes 9° and 13° N., but production is centred in Zaria and Katsina provinces and the eastern part of Sokoto province. The climate and vegetation of this area have been described by King [3], and the soils by Doyne, Hartley, and Watson [4]. Cotton grows best on moderately heavy soils where the average rainfall is

30–50 in. In Nigeria it is grown on small farms by peasants; the type of farming and the system of land tenure have been described by the author [5].

TABLE 2. *Distribution of Nigerian Cotton (Lint) Exports*

Importing country	*Weight ×1,000 cwt.**	*Per cent. of total*	*Weight ×1,000 cwt.**	*Per cent. of total*
	1935		*1938*	
United Kingdom .	153	70·51	92	79·97
Germany . .	49	22·58	9	8·13
Spain . . .	10	4·61	Included in others	
Holland . . .	3	1·38	3·5	3·10
France . . .	2	0·92	3	2·74
Italy . . .	Nil	Nil	3	2·38
Others . . .	Less than 1	..	4	3·68
Total . .	217	100·00	114·5	100·00

* Calculated from figures for distribution by value. Owing to fluctuation in price during the season these figures may therefore not be absolutely exact.

Approximately 99·5 per cent. of cotton exported from the Northern Provinces is American Upland of the Allen variety (*Gossypium hirsutum*). The indigenous cotton of Northern Nigeria consisted of other species [6, 7]; they used to be bought for export but their cultivation has declined in favour of the more valuable Allen. The balance of 0·5 per cent. of the exports is composed of native types (largely *Gossypium vitifolium*) grown in the Middle Belt areas bordering on the Niger and Benue rivers. Here the high humidity and longer wet season favour pests and diseases which have a more serious effect on Allen cotton than on the native species.

There is a large native spinning and weaving industry and considerable quantities of cotton are used for home consumption and for internal exchange—including export to the neighbouring French territory—so that only the surplus is sold for the overseas market. For instance, although a considerable amount of cotton is grown in Kano province, normally only small quantities are sold for export, as the farmer's surplus over his own requirements is taken up by the local spinning industry in this densely populated area.

Returns to the farmer.—The yield of cotton varies with the soil, spacing, and time of planting, but on the average native farm it is probably not more than 150 lb. of seed-cotton per acre. On government farms, where the land has been manured, yields of 450 lb. per acre have been obtained [8]. Reliable figures for the cost of production on native farms are difficult to obtain. Most of the African growers are illiterate and suspicious of interrogation, so that little reliance can be placed on information obtained from them. The peasant farmer has not, as a rule, any alternative use for his labour and consequently does not place any monetary value on his own or his family's labour as a factor in producing the crop. As a consequence he tends to treat all cash received for the

crop as a profit; for instance, he will continue to plant cotton long after the optimum date, even though he knows that the yield will be poor, but he apparently considers even the reduced yield an adequate return for his labour.

It is possible, however, to estimate the gross return the farmer would receive on his cotton. On the Zaria type of soil the farmer might have from ½ to 1½ acres planted with cotton. The average price of seed-cotton in the 10 years before the war was approximately 1*d.* per lb. so that, assuming a yield of 150 lb. per acre, the gross return would be from 6*s.* 3*d.* to 18*s.* 9*d.* or, say, 12*s.* 6*d.* per acre. Prof. Forde [9] quotes typical returns from cotton farms as 12*s.* in Zaria province in 1937 and £1 at Missau in 1939.

Factors affecting Production

Price.—Although the amount of cotton sold for export in any year is directly affected by the price offered, it is obviously restricted by the quantity produced. As the crop is planted some 6 months before the price is known, production is governed largely by the previous season's price. Thus high prices tend to cause an increase in production the following year, and there is some evidence to show that rising prices during the previous buying season have a similar effect. The relation which the price of cotton bears to the general level of commodity prices is also important, because when a drop in cotton prices occurs unaccompanied by a fall in commodity prices, the production may increase, since more cotton must be sold to provide the farmer's minimum cash requirements. Distinction must be drawn between the amount produced and the surplus sold for export. Prices of cotton in the local produce markets are frequently higher than those ruling in the cotton markets, particularly in the more remote areas where export prices are reduced by the transport differential and an unsatisfied demand exists in the surrounding neighbourhood. In parts of Sokoto province in 1931, the prices in the native markets were approximately 3*d.* per lb., when the price in the cotton market was only $\frac{7}{10}$*d.* per lb.

Table 3 gives the average annual purchases of cotton in the Northern Provinces for each season (October to March) since 1915–16 together with average prices at Zaria [10].

Effect of other crops.—Cotton fits well into the agricultural economy of the African farmer. In general it is not planted until after the main food-crops have been sown, and although there is some overlap in harvesting, the greater part of the cotton crop need not be picked till the harvesting of food-crops is finished. Only groundnuts compete seriously with cotton as a money crop, and the relative prices of these two crops have considerable influence on the quantity of cotton produced.

Yield and climate.—Good rainfall at the end of the growing-season is an important factor in promoting high yield. In the chief producing districts, the precipitation during October averages less than 1 in., but in some years it may reach 2 in. and over, and then the yield of cotton is above average—due to the prolongation of the growing-period. The

early onset of the harmattan has the opposite effect. It dries the plants, causing an early cessation of growth and increasing the amount of immaturity in the lint [8].

TABLE 3. *Cotton Purchases in Northern Provinces. Bales of Lint of 400 lb. each*

Period		*Season*	*No. of bales of American cotton*	*Av. price per lb.*	*No. of bales of native cotton*	*Total no. of bales*
1915–19	Average	..	914	..	..	914
	Highest	1918–19	2,248	2·75*d.*	..	2,248
	Lowest	1915–16	121	1·75*d.*	..	121
1919–29	Average	..	16,888	..	1,265	18,153
	Highest	1925–6	37,360	2·125*d.**	1,464	38,824
	Lowest	1919–20	3,568	3·75*d.**	..	3,568
1929–39	Average	..	28,036	..	1,478	29,514
	Highest	1934–5	50,322	1·1*d.* rising to 1·5*d.*	3,107	53,429
	Lowest	1931–2	4,811	0·6*d.* rising to 0·8*d.*	202	5,013
1939–46	Average	..	31,728	..	1,340	33,068
	Highest	1940–1	65,963	1·0*d.* rising to 1·3*d.*†	2,396	68,359
	Lowest	1944–5	12,451	1·7*d.*†	745	13,196

* Highest price was 4·5*d.* in 1920–1 with a total of 9,429 bales, and lowest price was 1·125*d.* rising to 1·75*d.* in 1926–7 with a total of 17,681 bales.

† Highest price was 2·1*d.* in 1945–6 with a total of 34,462 bales, and lowest price was 0·8*d.* rising to 1·1*d.* with a total of 49,332 bales in 1939–40.

Pests and diseases.—A list of insect pests affecting the cotton plant in Nigeria is given by Golding [11]. Cotton stainers, by discolouring the lint, lower the value of the cotton, and bollworms damage the bolls and prevent them from ripening. Of the parasitic diseases, angular leaf spot is present, and the virus diseases causing leaf-roll, leaf-curl, and mosaic symptoms are found. Although the damage done by these pests and diseases is by no means negligible, they are not sufficiently serious to render the crop unprofitable.

Effect of the war.—During the Second World War cotton had a relatively low priority for shipping space and this fact reduced exports. From 1943 onwards the maximum production of groundnuts was required, and as this could be obtained only at the expense of cotton, farmers were discouraged from growing it in the best groundnut areas. At the same time, cotton markets were confined to the southern part of the area, where groundnuts do not give as high a yield as farther north. Further, the total labour available was reduced by the departure of young men to the armed forces and to work at the tin-mines. Cotton was still produced for local consumption, and in increasing quantities owing to the shortage of imported cotton goods and their rising price. The price of cotton, as of other commodities, rose steadily in the local produce markets during the war period. The price of cotton for export was controlled by Government.

Organization of Markets.—All cotton sold for export has to be brought to a cotton market where it is graded by Government and purchased by the exporting firms. Most of the markets consist of temporary structures built of locally woven grass mats supported on poles cut from the bush. They are divided into a grading shed, where the cotton is examined and graded by a Cotton Examiner employed by the local Native Authority, and a buying shed, which is entered direct from the grading shed and has two compartments, one for Grade I and one for Grade II cotton. Each part of the grading shed is divided into booths or stalls which are allocated by ballot to the buying firms. In small markets the buying shed is controlled by the Cotton Examiner, but in the larger markets it is in charge of a Produce Examiner, an employee of the Government Agricultural Department. The cotton is purchased by African clerks employed by the buying firms. Each stall must be furnished with a scale for weighing the cotton. The markets are situated close to a village or town on a main road or on a dry-season road in order to facilitate evacuation of the cotton. Where the volume of cotton warrants it, it is considered desirable to site the markets about 15 miles apart as this affords all farmers an easy day's journey to and from the nearest market; but buying firms frequently favour larger markets farther apart in order to reduce the costs of purchasing.

Farmers usually bring their seed-cotton to market in baskets or wrapped in a cloth. The use of containers made of grass mat or Guinea-corn stalks is prohibited as cotton may become contaminated by pieces of grass from the container or by dust and dirt. To prevent buyers issuing bags to farmers and so acquiring a lien on the cotton, sellers are not permitted to bring cotton to market in gunny bags. When it reaches the market the cotton is spread out on mats in the grading shed where it is examined and graded by the Cotton Examiner. Three grades are recognized, but Grade III is not usually bought for export. If the cotton is on the borderline between two grades, the examiner may allow the seller to pick over the cotton in the grading shed and remove impurities so that it may reach the higher grade. The examiner gives the seller a grading ticket to show that the cotton has been examined, the colour of the ticket indicating the grade assigned to it. The seller then passes to the buying shed, at the entrance to which a doorkeeper is posted to ensure that sellers enter the correct buying-shed for their grade of cotton. The cotton is taken to one of the firms' buyers who weighs it and hands the cash value to the seller. The buyer receives the grading ticket and on this he enters the weight of the cotton and the amount paid for it.

The buyers retain all grading tickets and at the end of the day hand them over to the Produce Examiner or Cotton Examiner in charge of market, who totals the amount of each seller's purchases and checks it with the daily return of purchases submitted by each firm. The buyers pack the seed-cotton into bags, which are sewn and then sealed by the examiner with a lead seal. The seals are pressed with a hammer-press bearing the imprint of a number allocated to the particular market. By this means the cotton can subsequently be traced back to the market where it was purchased. The cotton purchased is removed from the

market daily to the firms' canteens or storage plots. Cotton is usually stored in the open until the end of March when the first rains may be expected.

Purchasing is carried out by eight West African merchant firms who have branches in Nigeria and by certain private Syrian firms and individuals; their trading organization has been described by the author [5].

The cotton-growing districts are divided into Market Areas, where the quantity of cotton produced is sufficient to justify markets being sited at fairly close intervals, and Buying Areas, where the cotton farms are more widely scattered and the markets consequently have to serve wider areas. In the former middlemen are prohibited from operating, but in the Buying Areas middlemen are allowed to purchase cotton under government licence. The middlemen are employed by the trading firms, and, whilst the more wealthy buy cotton with their own money, the majority receive advances from their employers for this purpose. Usually they buy seed-cotton at the farmer's homestead, but alternatively they may buy the growing crop and harvest it themselves. They have to judge the grade of cotton offered and frequently clean it before taking it to market. Middlemen's cotton has to pass through the market in the same way as a farmer's.

Ginning.—All ginning—separation of lint from seed—is carried out by the British Cotton Growing Association (B.C.G.A.). In 1939 it had seven ginneries in operation, each capable of turning out 50–100 bales of lint of 400 lb. each per day. Each ginnery serves a definite area and all cotton bought in that area must be sent to the ginnery serving it. The ginneries are operated by producer-gas made from cotton seed. The gins are of the saw type, and the normal ginning outturn is 29–31 per cent. of lint.

When bags of cotton are opened at the ginnery the cotton may be inspected by a Produce Examiner in order to check the grading and ensure that no adulteration has taken place.

The firms pay the B.C.G.A. a ginning charge based on the quantity of lint produced. (In 1939, at Zaria ginnery, this was $\frac{11}{16}d.$ per lb. of lint.) The disposal of the seed is controlled by Government, which requisitions sufficient to distribute to farmers for planting the next year's crop. An additional amount is purchased by Government for stockfeeding on experimental farms, and the B.C.G.A. retains sufficient to provide fuel for the ginneries. The balance is handed over to the firms for export, but any not exported must be destroyed.

Season.—The buying season is from November to March, but the opening dates of the markets vary according to the district and the season. The peak period of marketing is from mid-December to the end of January.

Price.—The buying price of seed-cotton is based on the price that can be offered at Zaria ginnery and is quoted as pence per lb. to the nearest tenth of one penny. All increases or decreases are made in units of $\frac{1}{10}d.$ The price at other ginneries is the Zaria ginnery price less the transport differential of the ginned cotton. The price offered in the cotton market at the town in which the ginnery is situated is $\frac{1}{10}d.$ less

than the ginnery price, and in the outlying markets a deduction is made, representing the cost of transport of the seed-cotton to the ginnery. Before the war this was $\frac{1}{10}d.$ for approximately every 30 miles. Grade II cotton is bought at $\frac{1}{10}d.$ per lb. less than Grade I and Grade III at $\frac{3}{10}d.$ less than Grade I.

Transport

The methods of transport used in Nigeria have been described elsewhere [5] and the rates for cotton are similar to those described for groundnuts.[1] Nigerian Railway Motors charge 4*d.* per ton mile for seed-cotton and in 1939 zone rates were in operation on the railway for wagon-loads of 5 tons and over. The first zone was from 0 to 70 miles and the charge was 11*s.* 8*d.* per ton, which represents an average rate of just under 3*d.* per ton mile.

From ginnery to port.—Four of the ginneries are situated on the railway, two on main roads (30 and 40 miles respectively from railhead), and one—Lokoja—depends on river transport for evacuation. The freight rate by Government Railway Motors for pressed bales is 6*d.* per ton mile. The rail freight from Zaria to Apapa is 60*s.* per ton and from Zaria to Baro 40*s.* per ton for wagon-loads of 5 tons each, representing a rate of 1·16*d.* and 1·75*d.* per ton mile respectively. The freight on cotton seed is a flat rate from all ginneries of 30*s.* per ton to Apapa and 13*s.* 4*d.* to Baro, including the cost of railway motor transport to railhead. Cotton seed for planting is, however, carried free on the railway.

Ocean transport.—The ocean freight from Lagos (Apapa) to U.K. ports is 40*s.* per ton of 2,240 lb. for bales not exceeding 90 cu. ft. per ton, and to continental ports 40*s.* for bales not exceeding 1,016 kg. (2,235 lb.). Approximately $5\frac{1}{4}$ bales make 1 ton. In addition to freight, Government harbour dues of 4*s.* per freight ton and the companies' shipping charge of 2*s.* per ton have to be paid. The freight on cotton seed to the U.K. was 22*s.* 6*d.* per ton and harbour dues 2*s.* per ton.

State Aids to Production

It was early realized that the country was likely to be suitable for cotton-growing, and since 1912, when the Northern Nigerian Agricultural Department was formed, much of its activity has been devoted to this crop. In this work it has had the ready assistance of the British Cotton Growing Association and the Empire Cotton Growing Corporation, the former on the commercial side and the latter in its scientific aspects.

Breeding and botanical work.—In 1912 some American and other varieties of cotton were introduced from Uganda and grown on the Government experimental farm. Allen's longstaple was the most promising and gave a higher yield and a better quality of lint than any other introduced or indigenous variety. The seed was multiplied by selected farmers and from 1920 onwards was distributed generally. Breeding-work has continued and varieties from all parts of the world have been tested. Since 1927, selections have been made from Allen cotton, and

[1] All rates quoted are 1939 figures. These have risen considerably since the war.

after many disappointments a strain has been raised, Samuru 26 C, which promises to be an improvement on commercial Allen. The yield and quality are equal to Allen but the ginning percentage is higher by about 7 per cent. [12]. In 1926 the E.C.G.C. established a seed-farm at Daudawa in Katsina province in order to multiply strains of improved seed bred by Government botanists [13]. The E.C.G.C. continued to operate this farm until 1939 when it was handed over to Government, and it still forms a link in the Agricultural Department's seed-multiplication plan.

Cotton-seed distribution.—To ensure a supply of good seed for planting, Government distributes seed to farmers, free of charge, through the Native Authorities, who advise Agricultural Officers of the amounts of seed required in each district and pay for the cost of transport to the dumps. There are usually one or more dumps for each administrative district, and from these the seed is collected by farmers under the supervision of the Native Authority Agricultural Staff.

Legislation.—[14]. Marketing regulations were first introduced by Government in 1926 and additional regulations were passed in 1935, with minor emendations and additions from time to time. They provided for the inspection and grading of cotton and for the establishment and conduct of markets, market and buying areas, and for the disposal of cotton seed, as already described. The grades of cotton are defined as follows:

N.A. 1 (Nigerian American Grade I). American seed-cotton grown in Nigeria entirely free from native seed-cotton and containing not more than 5 per cent. by volume of immature seed-cotton and not more than 1 per cent. by volume of damaged or stained seed-cotton, which, as regards freedom from leaf and other foreign matter, conforms to the departmental standards fixed for that grade.

N.A. 2. American seed-cotton containing not more than 1 per cent. by volume of native seed-cotton and not more than 6 per cent. by volume of immature seed-cotton and 6 per cent. of damaged or stained seed-cotton, which as regards freedom from leaf or other foreign matter, conforms to the departmental standards fixed for that grade.

N.A. 3. Any other American seed-cotton containing not more than 3 per cent. by volume of native seed-cotton.

N.N. (Nigerian Native). Native or mixed seed-cotton containing not more than 30 per cent. by volume of damaged or stained seed-cotton and which, as regards freedom from leaf and other foreign matter, conforms to the departmental standards fixed for that grade. (Departmental standards for freedom from leaf and foreign matter are issued as instructions to examiners.)

All cotton buyers must be licensed annually (fee 1*s.*), and licences may be withheld from those who have been convicted of an offence against the regulations. Contravention of the regulations is punishable by a fine of £50 or 6 months' imprisonment, or both. The inspection scheme is financed by charging scale-fees for all scales used for purchasing cotton; £2 per scale in a grade-I stall, 10*s.* per scale in a grade-II stall, and 5*s.* per scale in a buying-area. The proceeds of these fees are

allocated each year between the Nigerian treasury and the Native Authorities according to their expenditure. An Advisory Committee appointed by the Governor, consisting of the Director of Agriculture, senior administrative officials, and representatives of the buying and ginning interests, advises Government on the working of the inspection scheme.

On the cultural side, American Cotton Areas are declared by the Governor, and in these only American cotton may be grown. In such areas cotton and hibiscus plants must be uprooted and burnt by March every year.

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THE PROBLEMS AND POSSIBILITIES OF WHEAT-GROWING IN AUSTRALIA

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In view of the intense interest in the world's food situation at present, it has been suggested to me that a critical account of Australia's capacity for wheat-production would be appreciated by experts studying the larger subject.

The conditions under which wheat is grown in Australia are rather unusual. The wheat-growing countries of the world which have the nearest approach to Australian climatic conditions are the Argentine, parts of India, and some of the countries bordering on the Mediterranean. Except in Tasmania, where the area under wheat is negligible, the summer season is too hot and dry for its successful growth, and the seed is therefore sown in the late autumn or early winter (April to June) and harvested in the late spring or early summer (November to December). In spite of the sowing season, all the varieties grown would be definitely classed as 'spring' wheats. Although light frosts occur regularly in the winter months, snow is practically unknown in the wheat-belt and the temperature during the day is such that the crop grows steadily from the time of germination till maturity without anything in the nature of a resting period.

Rainfall (total, incidence, and reliability) is the main governing factor in determining the limits of the wheat-belt as well as the yield per acre. Nearly all the wheat in Australia is grown in regions which have an average rainfall of between 10 and 15 in. during the active growth of the crop—April to October or May to November. In each of the four chief wheat-growing States, attempts have been made to grow wheat commercially with less than 10 in. of seasonal rainfall, but this is now considered 'marginal' country in which wheat-growing will have to take a secondary place to grazing. Where the rainfall exceeds 15 in. during the period of growth of wheat, other industries such as dairying, fat-lamb raising, and fruit-growing usually prove more profitable.

As the north of the Continent has a summer rainfall and the southern half has a predominantly winter and spring rainfall, the conditions are satisfied in a broken strip of country near the south coast in W. Australia, S. Australia, and Victoria, bending north through New South Wales to southern Queensland (Fig. 1). In the wheat-belt of the three southern States, the bulk of the rain falls during the growing-period, but in northern New South Wales and Queensland quite a large additional amount falls in the summer and autumn months, which is not an unmixed blessing to the wheat crop. If these rainfall requirements were the only criteria for successful wheat-growing, the available area would be quite large. No figures could be obtained for Queensland, but the total area which satisfies the conditions in the four main wheat-growing States is estimated at 155 million acres, made up of 50 m. acres in New South

3988.64

Wales, 46 m. in W. Australia, 32 m. in S. Australia, and 27 m. in Victoria.

Soils.—An important limiting factor is, of course, the nature of the soil covering. Wheat is grown on a great variety of soils in Australia from free-working sandy soils to fairly stiff clays, the best results being obtained from the intermediate types—sandy loams, loams, and clay

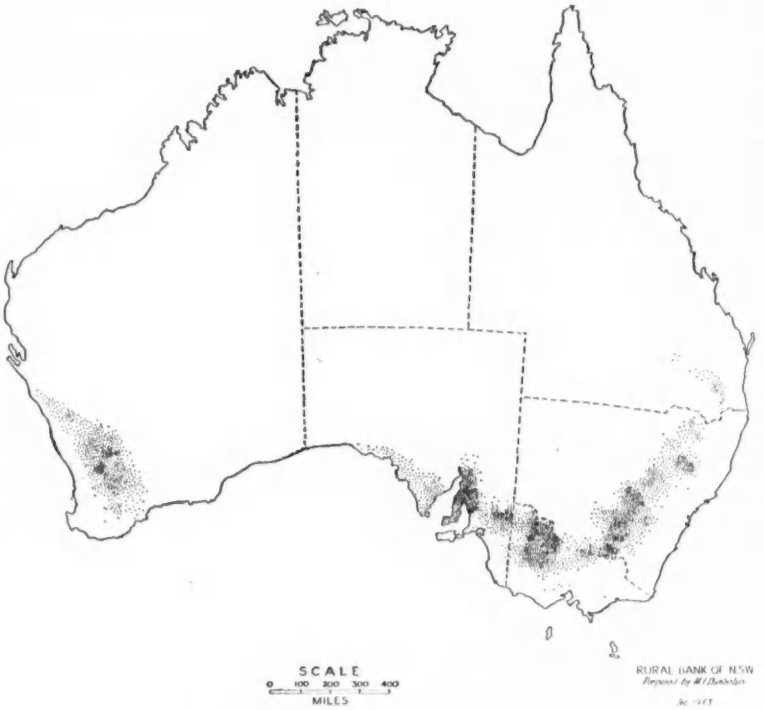

FIG. 1. Wheat-growing areas of Australia.

loams. More important than the actual texture of the surface soil are (*a*) the depth of soil and the nature of the subsoil, which must be deep, retentive of moisture and yet penetrable by moisture, air, and plant-roots, for it is found that under Australian conditions some of the roots regularly penetrate to a depth of 3 or 4 ft.; (*b*) the slope, which must not be too great or the damage from water erosion may prove too severe.

Very few virgin soils of the Australian wheat-belt are rich in humus or nitrogen, most of them contain satisfactory to abundant amounts of lime and potash, but all of those in the southern States and in southern New South Wales are very deficient in available phosphate. There are some indications of minor-element deficiencies, especially in W. Australia. It is only in recent years that nitrogenous fertilizers have been applied

and they are now used only in small quantities in conjunction with superphosphate on stubble land in the better rainfall districts. An excess of available nitrogen may do positive harm in the drier districts by inducing too leafy a growth, which renders the crop less resistant to drought conditions.

Except in Queensland and some parts of northern New South Wales superphosphate is almost invariably applied at the rate of ½ to 2 cwt.

FIG. 2. Average wheat-yields per acre.

per acre. The results from even such a small application as ½ or 1 cwt. are simply phenomenal, and many farmers would as soon think of leaving out the seed as leaving out the superphosphate, which is invariably sown in the same rows as the wheat by a combined seed and fertilizer drill. Fortunately for Australia in normal times an abundant supply of very pure rock phosphate is obtained from Ocean Island, Nauru, and Christmas Island and manufactured into a high-grade, free-running superphosphate in the Commonwealth. The occupation of these islands by the Japanese and the consequent difficulty of obtaining anything approaching Australia's superphosphate requirements was a major reason for cutting down the wheat acreage during the war.

Yields (Fig. 2).—Large-scale wheat-growing started in S. Australia, and the practice at first was to grow wheat almost continuously with the result that yields got so low that the average for a whole decade was under

5 bu. per acre. Largely through the influence of the late William Lowrie, two practices were introduced which in a comparatively short time doubled the average yield. One was the application of superphosphate already referred to; the other was the introduction of the cultivated fallow. This was practised first for the control of weeds but, in addition, it results in the conservation in the soil and subsoil of some of the rain which falls during the fallowing period, and also results in an accumulation of nitrates in the soil before seeding-time. The two practices gradually spread to the other wheat-growing States and resulted in cleaner crops and more abundant and stable yields there as well.

Another factor which has been of the very greatest benefit to the wheat industry in Australia has been the breeding of new varieties of wheat specially suitable to local conditions.

The wheats first introduced to Australia came from England and S. Africa and naturally were not particularly suited to their new environment. About the end of last century, when the export of wheat from Australia was just starting, the patient work of the late William Farrer was beginning to have important practical results and a few years later his varieties, especially Federation, were grown on more than half of the wheat area. Although his chief ambition at first was to breed rust-resistant varieties, he was much more successful with his other objectives —drought-resistance, early maturity, strength of straw, high ratio of grain to straw, and better quality grain. It is no exaggeration to say that the advent of the Farrer varieties raised the wheat-growing industry in Australia to a higher plane and was the means of extending it into much drier districts than previously thought possible. As recently as 1935, Federation was still the leading variety in New South Wales, and was very popular in the other States, but it would be difficult to find more than a few acres of any Farrer to-day for the simple reason that still better varieties have been produced by quite a number of other plant-breeders who were inspired by Farrer's example and success.

The average yield of wheat per acre year by year varies greatly with the weather conditions. In 1942 it reached 16·78 bu., whilst 2 years later (a drought year) it was only 6·25 bu. When yields are averaged over 10-year periods these differences even out and the general upward trend is clearly demonstrated by the following figures:

Period	*Av. yield per acre (bushels)*
1891–1900	7·32
1901–1910	9·82
1911–1920	10·69
1921–1930	11·99
1931–1940	12·54
1941–1947	12·67

The improvement in yield is really much more creditable than the figures indicate, as during the greater part of the period under review there was a gradual expansion of wheat-growing into drier and drier districts, whilst the yields during the greater part of the last 7 years were affected by war-time disabilities.

Profitability.—It may seem puzzling to those accustomed to British or European crops, averaging over 30 bu. per acre, how wheat-growing could possibly pay in Australia with even the improved yields of recent years, especially as the grain, besides a long journey by rail, has to be carried 12,000 miles by sea to its main export market. There are, however, many circumstances in Australia's favour. Land is cheap and wheat-growing is a large-scale, highly mechanized industry—one man with either a large horse-team or a tractor and a little additional help at harvest-time easily dealing with an area of 300 acres.

There is no need to plough deeply, and indeed a cultivator or scarifier is frequently used as a substitute for the plough; a bushel of wheat is sufficient to sow an acre, the cost of fertilizing is very low, and the methods of harvesting the grain very expeditious and economical, whilst transport costs are reduced to a large extent by handling in bulk. The Australian is a great horse-lover and teams of from 6 to 12 horses can still be seen in many districts ploughing and cultivating the land. The rapidly increasing use of the tractor has been an additional factor in improving yields as it is possible to get the work done quickly just at the very best time for each operation. In most districts and seasons, there is ample time for the preparation of a suitable seed-bed and hot dry weather is generally experienced at harvest-time. Australian wheat is popular on the world's markets owing to ease of milling, low moisture-content, and high yield of very white flour of satisfactory strength.

Hazards.—The chief hazards of the wheat-growing industry are the variability of the seasons and the incidence of diseases and weeds, although occasional severe local damage may be done by such pests as grasshoppers and rabbits. The main diseases which have reduced yields are bunt, flag-smut, take-all, and rust. Bunt (Tiletia spp.) is easily controlled by seed-treatment methods, which are almost universally practised. The most widely used fungicide is finely powdered copper carbonate, whose advantages over older methods were first discovered in Australia, although the new organic arsenicals are gaining in popularity. Flag-smut has been almost eliminated by the use of resistant varieties and take-all (Ophiobolus) greatly reduced by rotation of crops. More damage is probably done now by stem-rust than by all the others put together, but the production in recent years of quite a number of rust-proof varieties is certain to reduce its incidence very greatly in years to come. Most weeds are readily controlled by intelligent cultivation methods during the fallowing period, but there are some exceptions, e.g. skeleton weed (Chrondilla) whose spread is encouraged by cultivation. In some districts this is quite a serious pest and the only successful method of dealing with it is to lay the land down to pasture or grazing-lucerne for a few years. This, of course, has other benefits and some farmers are wondering whether its advent is not a blessing in disguise as it necessitates a longer rotation.

As in many other countries, the chief difficulty is the variability of the seasons. Temperature considerations are not of great importance, although in some seasons and districts quite considerable damage is done by unseasonable frosts at or near the pollinating period. Occasionally

there is delay in the preparation of the seed-bed through either too much or too little rain, so that the seed cannot be sown at the optimum time for any particular variety; also inconvenience and delay at harvest-time, especially in the northern section of the wheat-belt, may be experienced through untimely rains as the harvest season approaches. With regard to the latter, our plant-breeders have paid attention to strength and shortness of straw in breeding their new rust-resistant varieties, and improved harvesting methods have been devised for dealing with crops flattened by the rain.

Drought and soil erosion.—The main weather troubles, however, either arise from drought or are connected with soil erosion. An insufficient supply of soil moisture to meet the needs of the crop throughout the whole season of growth is the principal cause of reduced yields. The moisture requirements are particularly great about 'heading-out' time in September or October and, if a deficiency exists then accompanied by hot, dry winds, the grain harvest may be a complete failure. The practice of the cultivated fallow for 6–8 months before seeding is the best answer to this. With a reasonable rainfall during the fallowing period, the equivalent of from 2 to 6 or more inches of rain may be stored in the soil and subsoil and are just as effective as if they had fallen during the growth of the crop. By such means some remarkable results have been achieved of which two well-authenticated examples may be quoted.

At Inverell in northern New South Wales in 1927, a 32-bushel crop was grown with only 3·52 in. of rain during the growing season of the crop.

In the Western Downs district of Queensland, a yield of 24 bu. per acre was obtained from a 30-acre field on a rainfall of under 2 in. during the growing-period of nearly 6 months.

These are extreme examples and in each case the rainfall had been rather copious during the fallowing period, but they strikingly illustrate the principles involved, for each crop must have drawn on 5 or 6 in. of conserved moisture.

There are also many instances where wheat grown on fallowed land in a very dry year has given an average crop while that grown on stubble land was a complete failure. Fallowing, of course, has other beneficial effects, such as the accumulation of nitrate, owing to the conditions being favourable to bacterial activity over a considerable period without any drain on the nitrate-content by crops, weeds, or leaching. When the great benefits of the practice were first realized there was a rapid change-over from continuous wheat-growing to 'fallow wheat' or 'fallow, wheat, wheat' or 'fallow, wheat, oats', and there was much too great a tendency to over-crop the land, which has led to many disastrous examples of soil erosion. The system tends to deplete the soil of its limited amount of organic matter and humus so that it loses its natural crumb structure and its penetrability is decreased, whilst the leaving of the soil with little or no cover for months at a time renders it vulnerable to both wind and water erosion. The latter would not be so bad if the normal rainfall happened to be of the Shakespearian type, for it would easily be absorbed

by the fallowed land with its loose surface-mulch. Unfortunately, however, all too frequently it comes in the form of thunderstorms, when an inch or more may fall in an hour, and gullying or sheet erosion begins. During prolonged dry spells, too, much of the surface-soil may be 'gone with the wind'. A rough survey shows that something like half of the wheat land of Australia is detrimentally affected to a greater or less extent by either wind or water erosion. The majority of the farmers are now alive to the seriousness of the situation and a vigorous experimental and educational campaign has been organized to combat the evil. Districts with too small or too erratic a rainfall, and land with too steep a slope are being completely withdrawn from cultivation, and such practices as contour ploughing and planting, stubble-mulching, and contour draining are widely adopted; but perhaps the best method of combating the evil as well as maintaining soil fertility is the lengthening of the rotation. For climatic reasons, there are not many commercial annual crops which can be grown in rotation with wheat for grain, and the most widely grown are wheat and oats for hay and oats and barley for grain, which, of course, do not alter the general situation. The small flax and linseed industries, which had their origin in war conditions, overlap into the wheat-belt, but their permanence depends on suitable varieties and adequate prices. In the northern parts summer crops like maize and the grain sorghums come into the picture, but none of these helps to build up fertility or to prevent erosion.

Need of alternate husbandry.—From the experiences of other countries the obvious solution is to combine wheat-growing with some form of animal husbandry, so that fodder crops and temporary pastures may be introduced into the rotation. That is exactly what has been taking place and is likely to continue at an increasing tempo. On a very large proportion of the wheat farms of Australia some sheep are kept. In the drier regions the pure merino is favoured for its wool, but the more common practice is the use of merino or cross-bred ewes mated with rams of a mutton-breed for the production of fat lambs. In the most favoured parts of the wheat-belt dairying and even fat-cattle raising are combined with cereal-growing. When the price of wheat dropped so sensationally about 1929, many farmers took to pig-rearing and fattening and a few have found a very profitable side-line in the rearing of turkeys. The movement is all towards greater diversification although fat-lamb raising will probably, for many years, be the principal animal-husbandry supplement of wheat-growing. The two industries fit in very well if part of the farm is devoted to fodder crops and temporary pastures. This, of course, necessitates a smaller area under wheat which should, however, be largely balanced by increased yields per acre through the maintenance of soil fertility and reduction of the damage by erosion.

The future.—We have already seen that the area, excluding Queensland, which has the necessary rainfall for the growth of wheat, is 155 million acres, but nearly all the factors mentioned have to be taken into account when attempting to estimate Australia's capacity for wheat-production in the near future. There are still a few potential wheat-growing areas which lack railway facilities; and another important

unknown factor already referred to is the proportion of the area where the soil conditions are suitable.

I have been in communication with the heads of Departments of Agriculture of each of the wheat-growing States in order to make the estimate of future production as authoritative as possible and they all regretted that a sufficiently accurate soil survey had not been made of the present and potential wheat-growing areas of their particular States. Each, however, ventured an opinion as to the area which might reasonably be devoted to wheat in the comparatively near future, having due regard to the maintenance of soil fertility and the claims of other rural industries. The figures are set out in round numbers alongside the 'Basic acreage' used by the Wheat Industry Stabilization Board, based on the area normally sown by growers principally in the 3 years 1938–9 to 1940–1. This actually is about 2 million acres greater than the average of the 5-year pre-war period and 1 million acres more than the acreage sown in 1947, when the prospective price was attractive and many of the war-time disabilities had disappeared.

	Basic acreage	*Possible acreage*
New South Wales . .	5,000,000	7,000,000
Victoria . . .	3,300,000	4,000,000
South Australia . .	3,000,000	3,500,000
West Australia . . .	3,200,000	5,000,000
Queensland . . .	500,000	1,000,000
Total	15,000,000	20,500,000

My conclusion, therefore, is that the area under wheat in the Commonwealth could be increased to 20½ million acres in the next 10 years, and stabilized at about that amount provided that the price of wheat remains satisfactory and has a reasonable relationship to the prospective profits from other possible rural pursuits.

With a 13-bu. average this acreage represents an average annual production of 266½ million bu. compared with 154 million bu. in the pre-war period and an average of 132 million bu. in the last 8 years. In the present state of our knowledge that production could not be greatly exceeded without a loss in soil fertility; but that an urgent demand for a temporary increase in acreage could readily be met is indicated by the happenings of 1915 and 1930, when appeals were made for increased production. In the latter year the area under wheat for grain was approximately 18 million acres or 4 million acres more than in 1947 and only 2½ million acres less than the predicted future acreage.

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MILK AND MILK PRODUCTS IN INDIA

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MILK is often called the perfect food; it probably approaches perfection more closely than any other natural foodstuff. In these days of near world-hunger, actual and prospective, the importance of studying milk and its products cannot be overrated; and this applies particularly to tropical areas, including those of India, where there is great scope for improving supplies. In the present paper we have described briefly the general position in India to-day and have brought up to date certain statistical and other information, thus supplementing the extensive study made by N. C. Wright [1] in 1937 and the monograph by W. L. Davies [2] published a few years later.

In India dairying is essentially a village industry and almost every family keeps one or two milch animals to meet its requirements. For this reason the industry presents many peculiar features, and it is difficult to put it on a factory basis as has been done in Western countries. The outlook and the scope of the dairy industry are thus in many ways different from those accepted by the Western world. The gross milk production of the country is estimated as 6,129 million gallons [3]. About 90 per cent. of the milk produced in rural areas is utilized by the producers for their own use and for preparing milk products, the most important of which is *ghee*. The total quantity of milk utilized in urban areas is estimated at nearly 700 m. gal. per annum. Only about 6 per cent. of the total milk produced in the country is transported from the villages to urban centres for fluid consumption and for manufacturing milk products. Most of the milk consumed in urban centres is produced within the municipal limits.

Milk is obtained from two main sources, viz. cows and buffaloes. Nearly half of the total milk produced is buffalo's milk, 47 per cent is cow's milk, and the remaining 3 per cent. is obtained from goats, sheep, camels, and asses. The present general trend is that buffaloes are gradually replacing cows as milch animals, especially near the urban areas; for example, during the period 1920–40 the number of buffaloes increased by nearly 15 per cent., whilst the increase in the number of milch cows was only 2 per cent. This trend is largely due to the buffalo giving more milk and milk of higher fat-content than the cow, the buffalo being able as a rule to thrive on coarser feed. Though the total number of milch buffaloes is less than half that of cows, they contribute 50 per cent. of the total milk produced. The production of cow milk is concentrated in the Punjab (16 per cent. of the total), United Provinces (15 per cent.), Bengal (14 per cent.), Rajputana (12 per cent.), and Madras Presidency (10 per cent.). Buffalo milk is largely produced in the Punjab (27 per cent.), United Provinces (20 per cent.), and Madras Presidency (9 per cent.). The chief goat-milk producing areas are the Punjab

(22 per cent.), United Provinces (18 per cent.), Rajputana (9 per cent.), and Madras Presidency (9 per cent.) [3].

As a rule, the average milk yield per animal is very low and the recorded overall yield per day in the best animals varies from about 12 to 30 lb. The total milk produced by village units is thus very small, thus making collection and disposal on a large scale both difficult and costly.

I. *Composition of the Milk of Cows and Buffaloes*

The data for the chemical composition of milk of Indian animals was summarized by Sen and Dastur [4] and so only a brief summary is given here.

1. *Fat and solids-not-fat in milk.*—The outstanding characteristic of the milk of Indian animals is its richness in fat. The average percentage of fat in cow milk is about 4·5, and in buffalo milk nearly 6·0. Buffalo milk is also richer in solids-not-fat (S.N.F.). Individual animals (buffalo) give as high a fat percentage as 10–12 and fluctuations are observed in the fat and S.N.F.-contents of the milk of the same breed of animals even when kept under identical conditions. Kothavalla and Kartha [5] did not find any correlation between the level of production and fat-percentage in the milk of Hariana and Tharparkar cows. The fat-content of evening milk is usually higher than that of the morning milk and this difference is sometimes over one unit. Morning milk is, on the other hand, usually richer in S.N.F. than the evening milk.

Though milk cannot be said to be produced in villages under ideal conditions, a comparison of the average composition of authentic milk samples from village animals and animals maintained on larger dairy-farms has not revealed any striking difference in fat and S.N.F.-content [6, 7]. The total nitrogen is as a rule higher in buffalo milk than in cow milk [8]. The relative amounts of various nitrogen fractions in the milk of Murrah buffalo were studied at this Institute over a period of one year. The percentage distribution was found to be as follows:

Total protein nitrogen	91·7
Casein nitrogen	73·3
Albumin and globulin nitrogen . .	18·4
Total non-protein nitrogen . . .	8·3

Murrah buffalo milk contains, on an average, a higher percentage of total nitrogen, albumin, and non-protein nitrogen than the average figures given by Davies [9] for cow milk.

Singh and Dastur [10] do not report any difference in the chemical composition of cow and buffalo milk-casein.

2. *Mineral constituents.*—Brahmachari [7] found that the average percentage of ash in 1,187 market milk samples was 0·72, the range of variation being 0·60 to 0·80 per cent. Anantakrishnan *et al.* [8] found no difference in the total ash-content of cow and buffalo milk, though there was an appreciable difference in the distribution, as shown below (percentages):

Cow milk . . .	CaO ·127	P_2O_5 ·092	MgO ·014
Buffalo milk . . .	CaO ·163	P_2O_5 ·101	MgO ·013

Ray Sarkar [11] also found no change in the total ash-content of milk with season.

3. *Lactose and chloride in milk.*—Nearly 2,000 samples of milk have been examined recently at this Institute. The average lactose percentage of cow milk was 4·9 and of buffalo milk 5·3. Buffalo milk is thus richer but it contains much less chloride: the percentages found were 0·092 for cow milk and 0·066 for buffalo milk.

4. *Freezing-point of milk.* In recent studies at Bangalore no significant differences were found between the freezing-points of cow and buffalo milk, the average figures being −0·548° C. and −0·549° C., respectively.

5. *Effect of heat on milk.*—In India milk is almost always boiled before consumption. The nature of heat treatment varies from locality to locality. Anantakrishnan *et al.* [8] have studied the effect of heating milk on its chemical composition. On first boiling, the volume of milk decreased by about 6 per cent. This change in volume completely masked the change in composition, but after correcting for loss of water, the milk was found to lose about 5 per cent. of the main constituents in skin and precipitated matter. As the time of heating was extended, this loss increased. Skin and residue obtained from boiled milk samples contained on an average 49·3 per cent. fat, 28·1 per cent. protein, and 4·4 per cent. ash. The ash was rich in calcium and phosphorus. In comparable work in Great Britain Andross [12] concluded that about 10 per cent. of the nutrients of milk was lost on boiling. Recently some work has been carried out at this Institute to find out the nutritive value of raw and boiled cow and buffalo milk, as determined by the growth method. Milk was fed *ad libitum* to rats of 28 days' age. Cow and buffalo milk were adjusted to the same fat percentage each day with respective separated milks. No difference in the growth-rate was observed.

6. *Composition of colostrum.*—Buffaloes appear to have a shorter colostral period (3–4 days) than cows (4–6 days) [13, 14]. The colostrum of Indian animals is richer in proteins and ash constituents than Western breeds [15]. The trend of the general changes in all the constituents is, however, similar to that noted for Western breeds of cattle.

Determinations carried out at this Institute on the freezing-point of milk during the colostral period have shown that it is higher than that of normal milk: that of Sindhi cows is −0·581° C. and that of Murrah buffaloes −0·588° C. This is in line with the observations of Elsdon [16].

II. *Composition of the Milk of Goat and Sheep*

Comparatively few studies have been made of these milks. Bunce [17] gives the average fat-content of 30 samples of goat milk as 3·97 per cent. and the average S.N.F. as 9·88 per cent. Detailed studies of Surti goat milk and North-Gujarat sheep milk have been carried out recently at this Institute and the results (hitherto unpublished) are given in Table 1; data for cow and buffalo milk are also given for comparison.

The milk of goats and sheep appears to be richer in nitrogenous constituents, total ash, chloride, and ascorbic acid than cow milk. Goat milk approaches in composition cow's milk in its content of fat, S.N.F., and lactose, whilst sheep milk resembles buffalo milk in this respect. Holmes

et al. [18] have recently summarized data on the composition of milk from different species, and the values of different workers seem to show wide divergence.

TABLE 1. *Average Percentage Composition of Cow, Buffalo, Goat, and Sheep Milk*

Constituent	*Surti goat milk*	*North Gujarat sheep milk*	*Sindhi cow milk*	*Gir cow milk*	*Murrah buffalo milk*
Fat	4·30	6·40	4·65	4·54	6·30
Solids-not-fat	8·84	10·00	9·32	9·18	9·85
Lactose (hydrate)	4·67	5·06	4·92	4·86	5·30
Chloride (Cl_2)	0·16	0·11	0·09	0·09	0·06
Ash	0·81	0·84	0·71	0·71	0·72
Calcium	..	..	0·13	0·13	0·16
Phosphorus	..	..	0·09	0·09	0·10
Magnesium	..	..	0·01	0·01	0·01
Citric acid	..	..	0·22	0·21	0·19
Total nitrogen	0·61	0·89	0·57	0·56	0·60
Casein nitrogen	0·47	0·70	0·43	0·43	0·44
Albumin and globulin nitrogen	0·10	0·13	0·10	0·09	0·12
Non-protein nitrogen	0·04	0·06	0·04	0·04	0·05
Ascorbic acid (mg./100 ml.)	3·18	5·22	2·31	2·33	2·64
Freezing-point (−° C.)	0·579	0·589	0·548	0·548	0·549

Examination by us of 34 *market* samples of goat milk gave average lactose 4·42 per cent. and chlorine 0·125 per cent. The chloride-content of goat milk was nearly 40 per cent. higher than that of cow milk. The lactose and chloride contents of sheep milk were 5·06 and 0·109 per cent. The freezing-point depression of goat and sheep milk was also found to be higher than that of cow or buffalo milk.

III. *Composition of Milk Products*

It is estimated that nearly 72 per cent. of the milk available for the market is utilized for the manufacture of milk products. The relative quantities of milk, expressed as percentage of the total utilized for the manufacture of different products, are shown below [3]:

	Per cent.
Ghee (dry butter-fat)	79·2
Dahi (sour milk or curd for direct consumption)	7·2
Khoa (desiccated milk)	6·9
Butter (for table use)	2·4
Cream	0·5
Ice cream	0·5
Other products	3·3

An interesting feature of the dairy trade is that all the indigenous milk products, except *ghee*, give a much better return than the sale of fluid milk, the prices varying from 1·5 to 2·5 times the price realized for milk.

The methods of manufacture of the products vary in different localities. Except for *ghee*, the composition of various milk products has not been studied in detail. Davies [2] has given approximate figures

for the composition, but some of them require revision in the light of present knowledge.

1. *Dahi* is prepared by souring milk with a lactic-acid starter. Either raw or boiled milk is used, preferably the latter. Next to milk, *dahi* is the most important milk product, since the butter to be used for making *ghee* is produced by churning it. Sometimes sugar is also added to the milk before souring. Good *dahi* has a desirable lactic flavour, a solid and smooth texture, and is free from gas holes. It may be consumed within 24 hrs. after inoculation of the milk or it may be stored longer. The approximate percentage composition of good *dahi* is: water 85–88, fat 5–8, proteins 3·2–3·4, lactose 1·0–4·5, lactic acid 0·7–1·5, and ash 0·70–0·75. Both cow and buffalo milk are used for the preparation of *dahi*.

During the formation of *dahi*, the fat of milk has a tendency to concentrate on the top layer. Anantakrishnan and Kothavalla [19] have made a detailed study of the fat distribution. Depending on the size and shape of the vessel used, the concentration of fat in the top-quarter layer varied from 49 to 90 per cent. As the depth of the vessel decreased, the percentage of fat in the top layer increased, with the result that under ideal conditions over 90 per cent. of the total fat could be recovered in the top-quarter layer. A more uniform distribution of fat in *dahi* could be secured if milk were stirred 3–4 hrs. after inoculation, i.e. just before coagulation began. We have found that during souring the percentage of lactose decreases with the length of storage. After 24 hours' souring at 37° C., the lactose-content of milk decreased on an average by about 40 per cent., and after 7 days' storage by nearly 48 per cent. The lactose in buffalo milk appears to ferment more rapidly than that in cow milk. For example, the proportion of lactose destruction in cow and buffalo milk after 7 days' storage as *dahi* is about 48 and 72 per cent. respectively. In raw milk, about 21 per cent. of total calcium is soluble (dialysable); after souring for 24 hrs. it increases to over 60 per cent. On further storage of curds, this increase slows up until after 7 days it amounts to only some 69 per cent. with cow milk and 64 per cent. with buffalo milk. The average soluble (dialysable) phosphorus-content of raw milk is 22 per cent., and this increases to 39 per cent. when milk is curdled; on storage of curds for 7 days it amounts to 46 per cent. Ranganathan and Narasimhamurthy [20] found that a little nitrogen was lost on prolonged fermentation. During the process of souring milk, the non-protein nitrogen increased, but this increase was not proportional to the duration of fermentation.

2. *Makhan* is an indigenous variety of butter obtained by churning *dahi*. As most of this butter is used for conversion into *ghee*, the production is not carried out under controlled conditions. *Dahi* may be kept for nearly a week before churning. The amount of water added during churning varies from 50 to 200 per cent. of the *dahi*. The butter obtained is not always washed with water and consequently contains some entrenched butter-milk. This butter may be converted into *ghee* at once or may be stored for some days. The ideal conditions for churning are—to prepare *dahi* from boiled milk with an acidity of about 1·0 per cent. lactic acid, and to dilute the *dahi* with an equal volume of water

during churning. The loss of fat is then about 8 per cent. *Makhan* may contain large amounts of water varying from 20 to 35 per cent.

The by-product of butter-making is butter-milk (*lassi*). Unlike creamery butter-milk, it is consumed freely by the producers. Its composition varies with the dilution employed, but as a rule it is richer in fat during summer months. Mitra and Mittra [21] give the following percentage composition for buffalo *lassi*: water 91·15, proteins 2·63, fat 1·21, ash 0·68, carbohydrates 4·31, CaO 15, and P_2O_5 10.

3. *Ghee* is prepared by heating butter at temperatures varying from 80° to 125° C.; the flavour varies with the temperature of heating and the process is regulated by local demand. Sometimes *ghee* is made in two stages: (1) the fat is roughly separated from the curd and moisture, producing raw or *Kachha ghee*; (2) when there is a market demand, this *ghee* is heated to remove all the moisture. Colour, grain structure, and aroma are important criteria determining the market quality of *ghee*. Both cow and buffalo milk are used; buffalo *ghee* is in special demand in the Bombay Presidency, Central Provinces, United Provinces, and the Punjab. Cow *ghee* commands a premium in Bengal, Madras, and some other parts of the country. *Ghees* from these two sources differ considerably in their physical and chemical properties. Buffalo *ghee* is white with a slight greenish tint, whilst cow *ghee* is yellow due to the presence of carotene; buffalo *ghee* has large grains and is hard; cow *ghee* has small grains and a loose consistency. Usually *ghee* produced during winter months fetches a premium, as it is supposed to keep better. When properly made, *ghee* can readily be stored for 6–8 months. Dastur [22] has reviewed the methods of preparing *ghee*.

Buffalo butter-fat has normally a higher Reichert and lower iodine value than cow butter-fat. The difference is very noticeable in samples of market *ghee*, and for this reason separate standards are usually prescribed for cow and buffalo *ghee* in different provinces. In certain localities, such wide fluctuations are found in the composition of *ghee* during some parts of the year that special seasonal standards have had to be laid down. This change in analytical constants is mainly due to difference in feeding and usually occurs in cotton-growing areas where animals are fed on large excess of whole cotton seeds. The normal Reichert value of cow *ghee* is prescribed as not less than 24, of mixed *ghee* as not less than 26, and for buffalo *ghee* as not less than 28. However, in all cotton-producing areas, for buffalo *ghee* values lower than 24 are allowed, and in some instances values as low as 17 are permitted.

Achaya *et al.* [23] have studied the range of variations of analytical constants of cow and buffalo *ghee*. Their results are summarized in Table 2.

TABLE 2

	Reichert value	*Polenske value*	*Iodine value (Wijs')*	*Saponification value*	*B.R. Index at 40° C.*
Cow *ghee* .	16·9–28·1	0·9–3·2	31·0–45·6	212·8–232·8	42·5–47·7
Buffalo *ghee* .	14·5–39·9	0·4–5·3	21·4–39·9	198·0–239·3	40·9–46·9

Achaya and Banerjee [24] have analysed samples of buffalo *ghee* of varying Reichert values. They found a striking inverse relationship between the contents of lower fatty acids and oleic acid, similar to that noted by Smith and Dastur [25] in the analysis of milk fat secreted during inanition. The effect of ingesting cotton seed was to increase both the oleic and the stearic-acid contents of butter-fat. Patel *et al.* [26] found that under identical conditions of feeding, the B.R. index and Polenske values were significantly higher and the Reichert, Kirschner, and saponification values definitely lower in cow than in buffalo *ghee*. Achaya *et al.* [23] found that the iodine value of cow *ghee* was about three units higher than that of buffalo *ghee* of the same Reichert value, there being an inverse relation between the two values in both species. The same authors give the palmitic-acid content of cow and buffalo milk fat as about 27 ± 3 per cent. as against 23 ± 3 per cent. reported by Hilditch [27].

Ghee is generally used for cooking and frying. A recent study at this Institute showed that it does not undergo any change in chemical composition when heated up to frying temperature (200° C.). No change was observed even when high acid *ghee* (6–7 per cent. oleic acid) or rancid *ghee* (peroxide values, 5–10) were subjected to similar treatment.

4. *Khoa* is obtained by rapid evaporation of moisture from milk; the concentration aimed at is between 5 and 6 to 1 when buffalo milk is used, and between 6 and 7 to 1 when cow milk is used. *Khoa* is always made in small lots, using about 4–6 lb. of milk. The heating is done on a direct fire in small pans with vigorous stirring, so that the whole process is over in about 15 minutes. This method is also commonly used by the milk dealers to judge the quality of milk to be purchased.

Properly made *Khoa* is compact, and there is no leakage of fat or moisture. It is smooth to the palate and there is no rubbery feeling. *Khoa* is consumed directly as well as for preparing various sweets. During its preparation some iron gets incorporated from the vessel used for its preparation. The approximate composition of *Khoa* is shown in Table 3.

TABLE 3. *Composition of Khoa made from Milk of Varying Fat-content*

	Moisture %	*Fat* %	*Proteins* % (*Moisture-free basis*)	*Lactose* % (*Moisture-free basis*)	*Ash* % (*Moisture-free basis*)	*Iron* (*p.p.m.*)
Cow milk: 4% fat .	31	30	28	36	5	132
,, 5% ,, .	25	34	30	32	4	161
Buffalo milk: 6% ,, .	29	32	24	34	4	140
,, 7% ,, .	28	41	24	31	4	127
,, 8% ,, .	23	44	22	30	4	151

5. *Chhana* is made by coagulating hot milk with lactic or citric acid, added in the form of sour whey or lime-juice. Milk is first brought to the boil with stirring and then curdled with acid. The clot formed is drained through muslin. As the coagulation is carried out at a high temperature, the total quantity of acid required is only about half to

one-third of that required to bring the milk to the isoelectric point of casein. The yield of *chhana* is about 20 per cent. of the weight of milk taken.

Chhana is a special product which is made chiefly in Bengal and invariably from cow milk. It is estimated that about 10 per cent. of the total milk produced in Bengal is used for making it. *Chhana* is not usually consumed as such, but as the base for the manufacture of a large variety of sweets. The percentage composition of cow milk *Chhana* is given by Mitra and Mittra [21] as follows: moisture 56·33; fat 21·97; proteins 14·72; carbohydrates 5·34; ash 1·64; CaO 50; and P_2O_5 32.

6. *Condensed milk and related products.*—Condensed milk of the type commonly used in Western countries is not made, but there are several indigenous products which resemble it in composition. Amongst these, *Kheer* approaches condensed milk closely in composition. It is prepared by heating milk directly on a fire in an open shallow vessel to one-third or one-fourth its original volume. Thanks to vigorous stirring, the product obtained is quite homogeneous.

TABLE 4. *Composition of Kheer prepared from Cow and Buffalo Milk*

	Moisture %	*Milk solids* %	*Fat* %	*Protein* %	*Lactose* %	*Ash* %	*Cane-sugar* %
Cow milk unsweetened .	53	47	15·5	12·2	16·5	2·5	..
,, sweetened . .	33	47	15·5	12·2	16·5	2·5	15–20
Buffalo milk unsweetened .	49	51	19·5	12·5	16·5	2·5	..
,, ,, sweetened .	29	51	19·5	12·5	16·5	2·5	15–20

Another condensed-milk product is *Rabree*. It is made by a method similar to that described for *Kheer*, except that during evaporation the milk is not stirred but the surface is gently fanned to help the formation of skin. When the skin forms, a part of it is broken (about $1\frac{1}{2}$ sq. in. at a time) with a bamboo splint and kept on the side of the pan above the boiling milk. The formation and breaking of skin is a continuous process requiring some skill. When the volume of milk has been reduced to the desired consistency, sugar is dissolved in it, and the layers of skin collected on the sides immersed in the sweetened milk. The process is finished off by heating the whole mass for a short period. In its preparation only small quantities of milk, 5–6 lb., are used at a time. Buffalo milk is preferred for the preparation of *Rabree*, which is largely consumed in northern India.

A product similar to *Rabree*, but to which whole rice or starch has been added, is known as *Khurchan*.

7. *Cheese* is not a popular item of diet mainly because animal rennet is used in its preparation. Some local varieties are known, the *Surti Panir*, *Bandal*, and *Dacca* cheeses being the most notable. *Surti* and *Bandal* are soft varieties. *Surti* is invariably made from buffalo milk, and *Bandal* from cow milk. In the preparation of *Surti* cheese, goat rennet is added, and the junket when ready is transferred in thin slices to special bamboo baskets. As the whey drains out, the coagulum is care-

fully inverted. This process is repeated three or four times. Salt is added when transferring the coagulum to the baskets. When the cheese becomes fairly hard, it is kept immersed in whey. The yield is about 38 lb. of Panir from 100 lb. of milk with 6 per cent. fat. The method of preparation of *Surti Panir* is described in detail by Kothavalla and Verma [28]. *Bandal* cheese is made by coagulating the hot milk with some whey or *Dahi*. The coagulum is then drained, mixed with salt, and made into small balls. It is consumed as such or after smoking.

Dacca cheese, the only hard variety of indigenous cheese, is made by coagulating milk with rennet. The curd is collected and placed in small bamboo baskets and allowed to drain. Weight is applied to facilitate the drainage. The cheese is removed from the basket after 3–4 days and cured at room-temperature for 10–14 days. It is afterwards smoked.

Recently experiments have been made to prepare active enzymes from vegetable sources for preparing cheeses. Attempts have been made to isolate an active preparation from the berries of *Withania Coagulans* [29, 30].

IV. *Vitamins in Milk Products*

Vitamin A. Sen and Ray Sarkar [31] have determined the carotene and vitamin-A contents of colostrum from 7 Hariana cows and found that carotene rose as high as 130 μg. per 100 ml. during the first 3 days, the vitamin-A value to 320 μg. The day-to-day variations in carotene and vitamin-A content were not so marked as those observed by Dann and Kramer *et al.* [32] on the colostrum of Western breeds.

Ray *et al.* [33] determined the blue and yellow values (Moore units) of the butter-fat in milk from different breeds. The average values found were $71 \pm 32{\cdot}03$ units for carotene and $115 \pm 35{\cdot}46$ units for vitamin A per 100 ml. milk. Sen and Ray Sarkar [31] found 4·7 μg. of carotene and 35·9 μg. of vitamin A per 100 ml. milk during the dry season. When liberal quantities of green fodders were available the values rose to 20·4 μg. carotene and 56·4 μg. vitamin A per 100 ml. milk.

Recently Ahmed *et al.* [34] used the spectrographic method to examine buffalo *ghee* prepared in the laboratory or purchased in the market. Out of 48 samples analysed, 20 samples contained less than 24 I.U. of vitamin A per gm., 16 samples between 24 and 30 I.U., and 12 samples more than 30 I.U. per gm. The average of all the samples was 25·4 I.U. per gm. They also reported that the process of clarification of butter as ordinarily used in Indian homes did not cause any loss of vitamin A. When stored at room-temperature in summer, the loss in vitamin A in 4 months varied from 2·5 to 22·5 per cent., and in 6 months, the loss was between 25 and 30 per cent. De *et al.* [35] found the total vitamin-A activity of fresh cow *ghee* to be 36·5 I.U. per gm. Market *ghee* samples had a vitamin-A content varying from 7·9 to 12·2 I.U. per gm.

Vitamin-B complex. Very little work has been done on the amount of these vitamins in milk and milk products. Swaminathan [36] found only 0·1 mg. of nicotinic acid per 100 ml. of milk. Chitre and Patwardhan [37] gave the average riboflavin-content of buffalo milk as 0·74 μg., the thiamin-content as 0·31 μg., and the nicotinic-acid content as 1·18 μg.

per gm. Swaminathan [38] states that cow and buffalo milk contain 0·4 μg. vitamin B_1 per gm. Lawrence *et al.* [39] in America found the nicotinic-acid content of milk to vary from 0·50 to 0·86 μg. per ml. Sarma [40] gave the pyridoxine (B_6) content of cow's milk as 1·8 μg. per ml. when estimated by the chemical method and 1·3 μg. per ml. when estimated biologically. Chitre and Patwardhan [37] stated that the riboflavin-content increased during souring of milk (average for milk 0·70 and for curd 1·02 μg. per gm.), nicotinic-acid content decreased (milk 1·18, curd 0·51 μg. per gm.), but there was no change in thiamin-content.

Vitamin C. Ray *et al.* [33] found that the vitamin-C value of milk of Indian animals was of the same order as that reported by foreign workers. Ghosh and Guha [41] showed that during the souring of milk, vitamin C tends to be stabilized and is less easily destroyed than in whole fresh milk. The curd retained the entire amount of ascorbic acid of fresh milk but there was no increase during souring. Chakraborty [42] claimed that vitamin C in buffalo milk was much more stable than in cow or goat milk.

V. *Nutritive Value of Milk and Milk Products*

Though work on the nutritional value of milk is only of recent date, Indians are usually very fond of milk and milk products whenever these are available. The value of milk and milk products for maintaining the body in good health has been recognized in this country from very early times and the beneficial effect of milk has been described at length in ancient Indian medical literature. Further, milk and its products, especially curds, are looked upon as auspicious and are freely consumed on festive and religious occasions.

Feeding experiments with milk from different species of animals have not revealed any outstanding differences in their nutritive qualities. Das and Guha [43] and Basak and Guha [44] found no difference in the nutritive value of cow, buffalo, and goat milk when correction was made for the total-solids content of each. Basu and Mukerjee [45] found that the phosphorus of cow, buffalo, and goat milk was equally well utilized.

The supplementary value of cow, buffalo, goat, and sheep milk in Indian diets which are known to be deficient in calcium, first-class proteins, and vitamins, have been under investigation for some time at this Institute. No significant differences have been observed between the supplementary effect of the milk from different species when measured by the growth of rats. Butter-fat or other vegetable fats alone had very little supplementary effect on a poor rice diet, whilst fat plus vitamins gave only half as much gain in weight per week as did the whole milk supplements.

Summary

1. In India, market milk is obtained from two main sources, namely cows and buffaloes. Milk from Indian animals is rich in fat. Buffalo milk is richer in lactose, albumin, and non-protein nitrogen than cow milk. It contains less chloride. The freezing-points of cow and buffalo milk are identical.

2. The milk of goats and sheep contain more chloride and ascorbic acid than cow milk. The freezing-point depressions of the milk from these two species are also higher than those of cow and buffalo milk.

3. The most important dairy product in India is *ghee*, i.e. clarified butter. Its composition varies widely and depends on the source of milk and on seasonal changes in the feed. The average composition of the fat of cow's milk is similar to that obtained from Western breeds.

4. Other important milk products are *dahi* (curds), *Makhan* (indigenous butter), *lassi* (butter-milk), *Khoa* (desiccated milk), *Chhana* (obtained by coagulating hot milk with acids), and various types of condensed milk.

5. The methods of preparation of different milk products, their composition, vitamin-content, and nutritive value are described.

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[In the above article 'India' obviously refers to the country before it was subdivided.—Edit.]

THE THREE-QUARTER-BRED HOLSTEIN-ZEBU HEIFER

PT. II. GROWTH FROM BIRTH TO TWO YEARS OF AGE

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THE Holstein-Zebu of Trinidad, like the Jersey-Sahiwal of Jamaica, has been developed as a tropical dairy animal by cross-breeding methods. The aim of crossing has been to combine the qualities of heat tolerance of *Bos indicus* with the capacity for high milk-production of *Bos taurus*.

The purpose of the investigations reported in the present series of communications was to establish physiological standards for this particular cross-bred under favourable conditions of feeding and management, and to determine the extent to which the advantageous and detrimental characteristics of its ancestral species are exhibited. In addition, the data collected during the course of the study provide information on the feeding-stuff requirements for rearing in Trinidad.

The duration of the study is from birth to the end of service in the milking herd. In Part I of this series we presented a study of the haematology of the Holstein-Zebu during the first year of life [1]. In the present communication we are concerned with the growth-period from birth to two years of age. In subsequent reports data on sexual maturity, breeding performance, and milk production will be presented.

To formulate rules of good management for rearing the experimental animals was not difficult because the experience of those responsible for dairy-herd management in Trinidad was available to us. Indeed, the measures adopted differ little from good practice under temperate-zone conditions except from the standpoint of specific measures for disease control.

To formulate feeding standards for rearing was less easy. First, it is possible to obtain different rates of growth in calves according to the plane of nutrition chosen, and it follows that all rates of growth are to some extent arbitrary. Secondly, little is known of the nutritional requirements of tropical dairy calves for any given rate of increase, although it is unlikely that the requirements of such animals differ markedly from those of temperate-zone calves having a comparable rate of growth. The main difficulty arises in another connexion. Under temperate-zone conditions roughage of good quality plays an important part in the nutrition of the growing heifer. In Trinidad this is not so. The roughage available to us was mainly of the coarse-leafed variety—elephant-grass (*Pennisetum purpureum*) and Guatemala grass (*Tripsacum laxum*)—and not only are these grasses of low nutritional value but the amount which animals will eat is low compared with temperate-zone stock consuming fine-leafed herbage [2, 3]. Greater recourse must be

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made to concentrates as a source of nutrients under such conditions and, in consequence, the general pattern of the rations bears little resemblance to those used for rearing dairy heifers under temperate-zone conditions.

The rationing system devised in the course of the experiment was based upon the appearance of the heifers. They were encouraged to consume as much roughage as possible and the concentrate allowance was adjusted to keep them in good but not high condition. A first approximation to our final rationing system was made during a preliminary study of other calves not included in the present experiment. Minor modifications in the amounts given were made on the basis of the behaviour of the first calves transferred at birth to the experiment.

Experimental

Animals.—The calves used in the study were those on which we reported in Part I, and the method of breeding to produce the three-quarter-bred was therein described [1]. Of the 18 animals selected for the experiment one died during the second year of life. Twelve animals contained one-quarter of Zebu blood: Nos. 1, 2, 6, 7, 9, 11, 13, 14, 17, 18, 19, and 20. The remainder, Nos. 4, 5, 8, 10, and 15, contained a lower but not accurately determinable proportion of Zebu blood. The above numbering will be retained throughout the present series of reports. The animals were not specially selected but were those heifer calves, approximately three-quarter-bred, born during a period of 7 months in the commercial herd at the Government Stock Farm.

General management.—The calves were transferred from the Government Stock Farm to the Imperial College Farm at 3 weeks of age and kept there until 12 months old, when they were returned to the Stock Farm. While at the College Farm they were penned each night. At the Stock Farm they were kept in two paddocks of savannah-grass (*Axonopus compressus*) with a roofed pen available for shelter. While at the College Farm they were turned into paddocks from 8 to 11 a.m. and from 3 to 5 p.m. daily. At other times they were in roofed pens. Three types of paddock were available: one of *Axonopus compressus*, one of *Brachiaria decumbens*, and one of *Indigofera endecaphylla*. The pens were cleaned daily and well provided with dry bedding.

The calves were drenched monthly against intestinal parasites using copper sulphate solution, beginning at 1 month of age; from 10 months they were protected against tick infestation by treatment every 2 weeks with an arsenical cattle dip.

Feeding.—The rearing-period, from birth to first calving, was divided into four intervals: the first from birth to weaning at 4 months of age, the second from weaning to 6 months, the third from 6 to 12 months, and the fourth from 1 year onwards after the heifers had been returned to the Government Stock Farm.

The feeding-system used during the first, or milk-feeding, period is given in Table 1. The milk allowance was increased gradually during the first 3 weeks to reach a maximum of 1 gal. daily. Weaning began at 12 weeks of age and was completed by the end of the 15th week. The

TABLE 1. *Feeding-system up to Time of Weaning, in Allowances Daily*

Age of calf (weeks)	*Milk (pints)*	*No. of milk feeds*	*Concentrate allowance (lb.)*	*Roughage*
0–3	4	3	Nil	Young grass
3–4	6	3	*ad lib.*	..
4–12	8	2	*ad lib.*	..
12–13	6	2	2	*Tripsacum laxum* and *Pennisetum purpureum*
13–14	4	2	3	
14–15	2	2	4	
15–16	1	2	6	..

total amount of milk received by each calf was about 90 gals. Each calf received its dam's colostrum. The milk allowance at each feed was diluted with 1 pint of lime-water and all milk was fed warm. During the first 3 months of life young grass of fine-leafed varieties was before the calves in racks at all times. The concentrates were offered *ad lib.* until weaning began. The rationing of concentrates began as milk allowances were reduced. The composition of the concentrate mixture used during the first and second periods is given in Table 2.

TABLE 2. *Composition of Concentrate Mixture given during the First and Second Periods*

Feeding-stuff	*Per cent.*
Maize meal	59
Oats	15
Wheat bran	10
Fish-meal	5
Linseed-oil meal	5
Soya-bean meal	5
Salt	1

During the second period, from weaning to 6 months of age, the concentrate allowance was continued at a level of 6 lb. per head daily. The fine-leafed indigenous roughage was replaced by fodder grasses, a mixture of equal parts of elephant-grass and Guatemala grass being in the racks at all times. An amount of roughage well in excess of requirement was offered so that the calves were not compelled to eat the coarser parts of the grasses. The calves also obtained roughage from the Brachiaria and Indigofera paddocks in this and the third period.

The third period, from 6 to 12 months of age, was characterized by a gradual reduction in concentrate allowance. The total daily concentrate allowance was composed of two parts: a protein supplement and an energy supplement. The composition of the protein supplement is given in Table 3. The energy supplement was crushed maize. The allowances of concentrates at different ages are given in Table 4.

TABLE 3. *Composition of Protein Supplement given during the Third Period*

Feeding-stuff	*Per cent.*
Linseed-oil meal	33
Soya-bean meal	33
Wheat bran	31
Bone-meal	2
Salt	1

During the fourth period, from 1 year of age onwards when the heifers were at the Government Stock Farm, they received a daily allowance of 5 lb. of concentrates. The mixture was that given at 8 months of age as recorded in Table 4. The increase in concentrate allowance was found to be necessary to compensate for the inferiority of savannah-grass grazing to the grazing of the Brachiaria and Indigofera paddocks at the College Farm. In addition to the grazing the heifers had a supply of unchaffed elephant-grass before them in racks at all times.

TABLE 4. *Daily Allowances Per Head at Different Ages of Protein and Energy Supplements given during Third Period*

Age (months)	*Crushed maize (lb.)*	*Protein supplement (lb.)*
6	4·5	1·5
7	4·0	1·5
8	3·5	1·5
9	3·0	1·5
10	2·5	1·5
11	2·0	1·5
12	1·5	1·5

The animals were not fed individually. They were grouped according to age and size and fed in pens with ample trough-space. Where any animal appeared to be getting less than its share of concentrates it was separated from the rest for a short time and given its concentrate ration. Up to 1 year of age lime-water as well as ordinary water was available in drinking-troughs at all times.

Methods

The calves were weighed at weekly intervals up to 6 months of age. Thereafter they were weighed fortnightly. All weighings were carried out in the morning before feeding and were made on 3 successive days to give an average value for each week or fortnight. Owing to the relative inaccuracy of weigh-bridges for low weights, a spring-balance was used for calves up to 250 lb. live-weight, the animal being supported in a canvas harness. For animals over this weight a weigh-bridge was used. Both the spring-balance and the weigh-bridge were checked by means of a set of standard weights before, during, and after all weighings.

Height measurements were made with the animals standing on a specially constructed platform with an upright carrying a metre scale over which moved a horizontal bar. To ensure accuracy of measurement a spirit level was attached to the moving bar. Readings were taken with the moving bar resting lightly on the withers and with the level indicating that the bar was horizontal.

Results

General.—The health of the animals remained good, in general, throughout the study. As mentioned in Part I, transient sporadic attacks of anaemia occurred in some animals. From time to time individuals showed poor gains, but such periods were of relatively short duration. When they occurred the animals in question were fed individually to ensure that they received their full ration of concentrates. The only serious adverse sign was heavy and laboured respiration, which was most marked during the night.

Live-weight.—The mean monthly live-weights, together with the ranges in weight, are given in Table 5 for the period from birth to 2

TABLE 5. *Live-weight of Three-quarter-bred Holstein-Zebu Heifers from Birth to 2 Years of Age*

	Live-weight				*Live-weight*		
Age (weeks)	*Mean (lb.)*	*Min. (lb.)*	*Max. (lb.)*	*Age (weeks)*	*Mean (lb.)*	*Min. (lb.)*	*Max. (lb.)*
Birth	61	43	73	56	472	379	529
4	72	52	88	60	506	389	584
8	102	79	124	64	518	420	617
12	139	108	177	68	549	425	656
16	180	149	226	72	572	455	682
20	219	173	272	76	595	460	716
24	258	206	310	80	623	476	726
28	293	229	364	84	646	491	768
32	321	238	399	88	664	484	789
36	349	268	448	92	688	499	829
40	371	279	467	96	714	531	840
44	394	299	483	100	745	548	864
48	425	326	509	104	769	598	893
52	454	366	524				

years of age. Average values only are given in the present communication. Should subsequent performance prove to be related to growth during early life the necessary data will be presented in later communications. As the earliest age at which calving occurred was 2 years and 4 months, these data should be free from the bias caused by the weight-increases associated with the last stages of pregnancy. In Fig. 1 the mean-growth curve of the Holstein-Zebu heifers is given together with the curves of Holsteins [4] and Indian Sahiwals [5] for purposes of comparison.[1]

[1] We use the term 'Holstein' to indicate Holstein-Friesians of Canadian and U.S. origin and the term 'Friesian' to indicate animals of the same breed but of British

The average birth-weight of 61 lb. for Holstein-Zebus is about two-thirds of the birth-weight of Holsteins and closely similar to the value of 60 lb. given by Littlewood [6] for improved Indian Nellore (Ongole) calves.

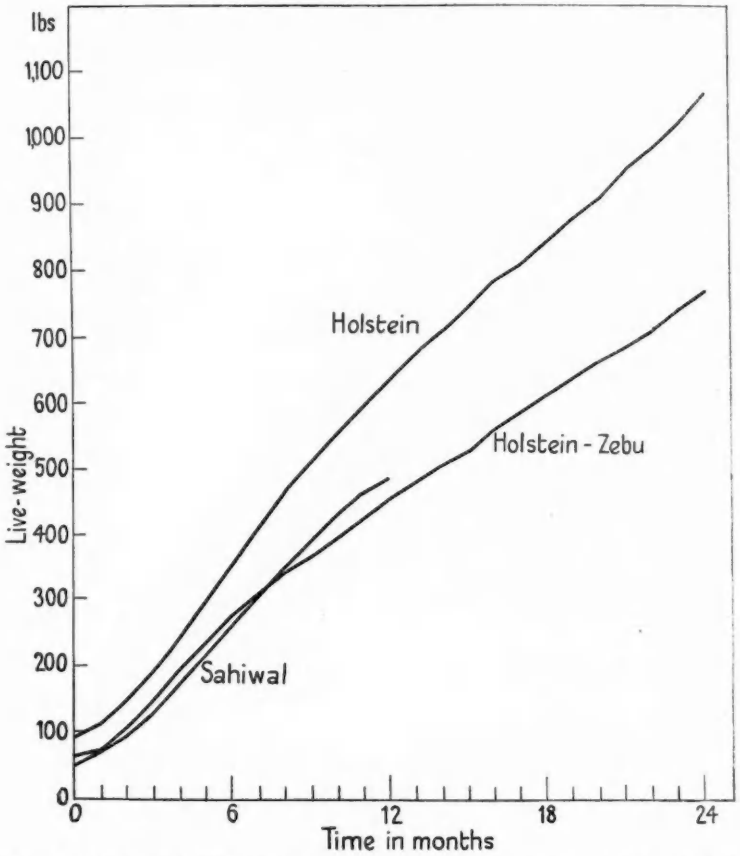

FIG. 1. The growth of Holstein-Zebu heifers from birth to 2 years of age with data for Holstein and Sahiwal heifers for comparison.

The weight-increases in the cross-bred heifers can be divided into three periods: the first, from birth to 4 months of age, when the monthly increments showed successive increases in magnitude; the second, from 4 to about 6 months, when the amount of increase reached in the 4 months was approximately maintained; the third, from about the 7th

and Dutch origin. Similarly, the term 'Holstein-Zebu' is used to indicate that the temperate-zone progenitors were of Canadian or U.S. origin and 'Friesian-Zebu' to indicate that the temperate-zone progenitors were of British or Dutch origin.

month to 2 years of age, when the growth continued at a lower level but in a manner almost linear. During the first of these periods the monthly increases in weight are somewhat less than in Holsteins but similar to those of the Sahiwals. During the second of the periods the divergence from the Holsteins becomes slightly more marked but the curve follows a course closely similar to that of Sahiwals. During the third period the divergence of the Holstein-Zebu curve from the Holstein curve becomes most marked and the growth of the cross-bred heifers is surpassed by the Sahiwals. The resemblance between the Holstein and Sahiwal curves is interesting. The break in the Holstein-Zebu curve at about 7 months contrasts sharply with the curves of these breeds representing the two parent species.

Comparisons of growths and growth-rates are difficult in cases where birth-weights and adult size are dissimilar. The *absolute growth* in Holsteins is somewhat greater than in Holstein-Zebus and Sahiwals during the first few months of life. In other words the actual weights of new tissue laid down daily are slightly greater. But because the initial size of Holstein-Zebus and Sahiwals is markedly less than that of Holsteins their lower daily gains represent a higher *rate* of growth; that is, the daily accretions are greater in relation to body-weight in these breeds than in Holsteins.

To facilitate comparisons of this type, Brody [4] developed the conception of the 'instantaneous relative growth-rate', and devised a method of evaluating this rate. The theoretical basis for the calculation is as follows: the differential dW/dt represents the 'instantaneous absolute growth-rate' and the expression $\frac{dW/dt}{W}$, or k, represents the 'instantaneous relative growth-rate', dW being the element of weight added during the element of time, dt, when the weight is W. On integrating for finite intervals of time the expression becomes: $k = \frac{lnW_2 - lnW_1}{t_2 - t_1}$. That is: the 'instantaneous relative growth-rate', k, is obtained by subtracting the natural logarithm of the weight W_1, as observed at time t_1, from the natural logarithm of the weight W_2, as observed at time t_2, and dividing this by the time interval $t_2 - t_1$. The values obtained for k when multiplied by 100 give the percentage relative rates of increase during successive intervals.

The percentage relative rates of growth for successive 2-month intervals are given as histograms in Fig. 2. The instantaneous relative growth-rates were calculated for 2-month intervals from the data presented in Fig. 1.

The relative growth-rate of the Sahiwal is strikingly greater than that of the Holstein during the first 4 months of life. Thereafter the difference is less marked, but it is only when the period of 10–12 months of age is reached that the Sahiwal's rate falls slightly behind the rate for the Holstein. At first the Holstein-Zebu shows a growth-rate almost equal to that of the Sahiwal but this condition no longer exists after 4 months

of age. From then until 10 months of age the Holstein-Zebus lag behind the other two breeds. From 1 year of age onwards data for Sahiwals are lacking. Results for Holstein-Zebu and Holstein show no consistent difference during this period.

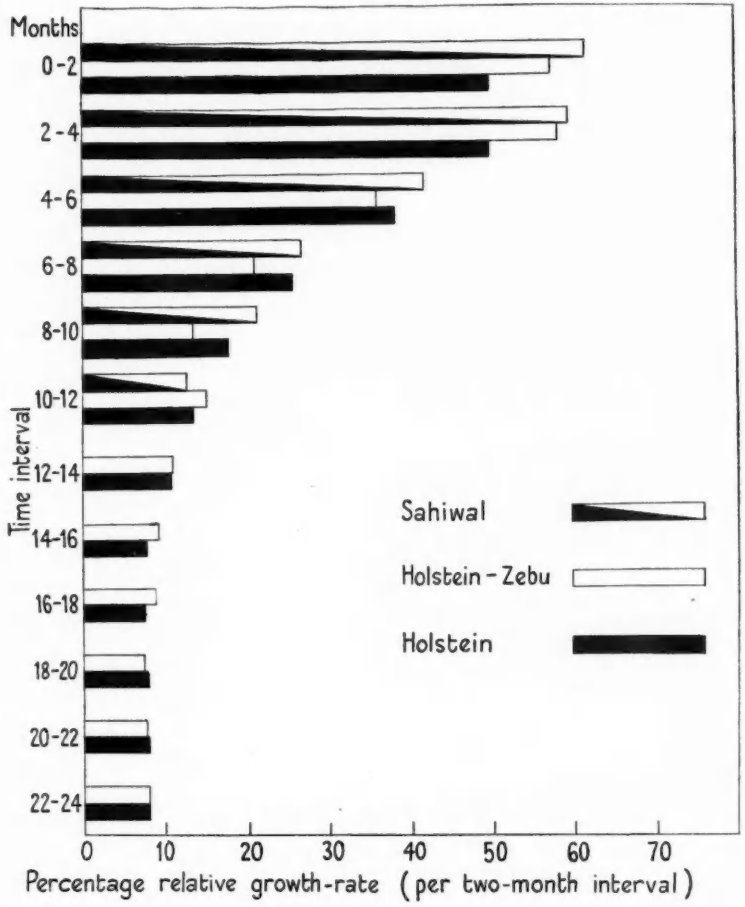

FIG. 2. The percentage relative growth-rates, for successive 2-month intervals, of Holstein-Zebu heifers, with data for Holstein and Sahiwals for comparison.

Height.—The average height at withers at different ages in Holstein-Zebus and Holsteins is given in Fig. 3. After an initial lag the Holstein-Zebu calves grow more rapidly than Holstein calves. At about 5 months of age growth begins to slow down in both Holstein-Zebu and Holstein calves. The reduction in rate is more marked, however, in Holstein-Zebus, and from this point onwards the height-curves diverge somewhat.

As the Holstein-Zebu calves are shorter at birth than the Holsteins the early phase of rapid growth represents an even greater relative growth-rate in cross-bred calves than in Holsteins up to about 5 months of age. The changes in height are thus closely analogous to those in weight.

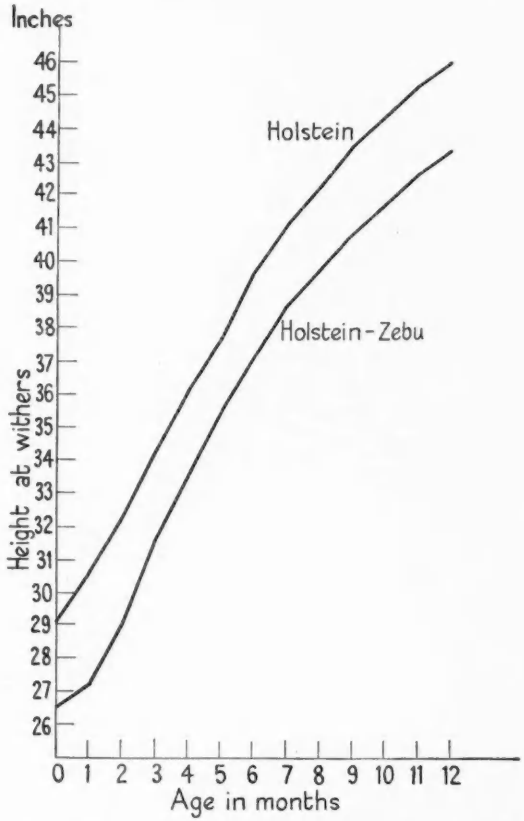

FIG. 3. Growth in height at withers of three-quarter-bred Holstein-Zebu heifers from birth to 1 year of age, with data for Holsteins for comparison.

Discussion

Before discussing the growth of the cross-bred heifers it is of interest to compare their feed-intakes with established standards. As mentioned earlier, we used the appearance of the animals as a guide and considered that the rations given were adequate if the heifers were in good condition. We did not aim at sustaining a high rate of growth. Thus we continued reducing the concentrate allowance during the interval from 6 to 12 months of age although the break in the growth-curve occurred

at 7 months because, in spite of the slower growth, the appearance of the animals was satisfactory.

Comparisons with the Morrison [7] feeding standards for dairy heifers at different body-weights are given in Fig. 4. The protein requirements,

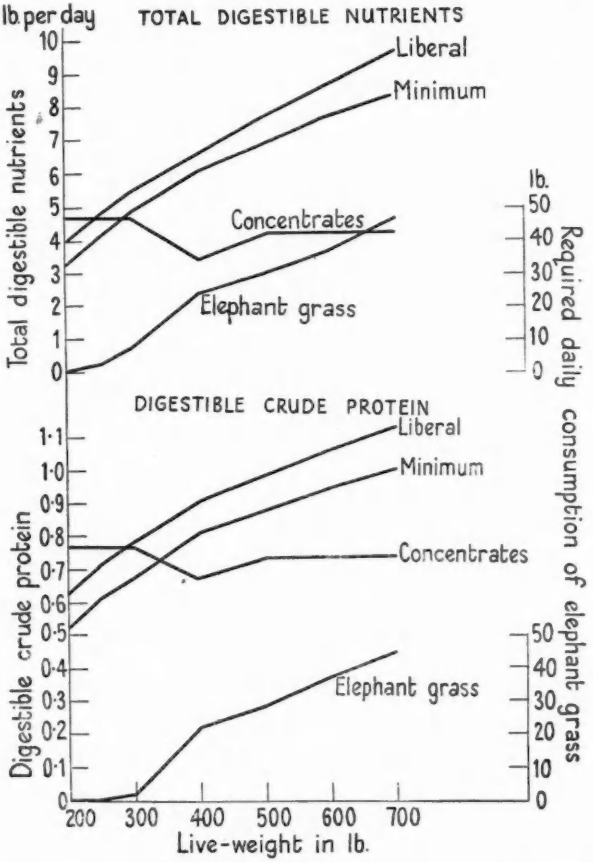

FIG. 4. The liberal and minimum Morrison standards for total digestible nutrients and digestible crude protein for growing dairy heifers, together with the contributions made by the concentrate allowances in the present study and the deficits from the liberal standard to be made up by elephant-grass.

as digestible crude protein, and the energy requirements, as total digestible nutrients, are shown. For each of these categories Morrison gives two limits: the liberal allowance and the minimum allowance. Both allowances are shown in the diagram. In addition, the digestible crude protein and total digestible nutrients provided daily by the concentrates are shown for each weight-interval. The differences between

the amounts of protein and energy provided by the concentrates and the corresponding standards at any given weight indicate the deficits to be made up by roughage consumption. In each case the quantity of elephant-grass which must be consumed daily to bring the total intakes of protein and total digestible nutrients up to the levels of the liberal allowances are given in the diagram.

It will be noted that the quantities of grass to be consumed at different live-weights is not excessive, in spite of the low nutritive value of the grass. The quantities of elephant-grass shown in the diagram, combined with the concentrates, yield sufficient nutrients to meet the liberal standard which, incidentally, is sufficient to sustain a degree of growth in American Holsteins similar to that recorded in Fig. 1. It was shown elsewhere [2, 3] that the average daily consumption of chaffed elephant-grass by adult Holstein-Zebu cows of 825 lb. mean live-weight was 51 lb. or about 6 per cent. of the body-weight. The amounts of elephant-grass shown in Fig. 4 are generally of this order. It is emphasized, however, that the value of 6 per cent. for adult cattle was obtained when feeding chaffed elephant-grass with the coarse parts of the stems included. The heifers in the present study had long elephant-grass and Guatemala grass before them at all times together with access to grazings of fine-leafed grasses. By selective feeding they were able to secure the more nutritious parts of the available roughage and thus reduce the intake needed to raise the total consumption of feed to levels of requirement.

In spite of the adequate provision of nutrients the growth of the three-quarter-bred heifers was much inferior to that of Holsteins. This is surprising in view of their close genetic relation to the parent breed. Although it will be some years before growth is complete, the impression given by the cross-bred cattle is that they will finally reach the size of the Nellore cattle used in the first cross, that is, their mean live-weight will be about 1,050 lb. That the diminished growth was an overall reduction in size, as compared with Holsteins, and not the result of the development of a 'leggy', shallow frame, is shown by the comparable reduction in height at withers.

But the general nature of the growth-curve is not merely a repetition of the Holstein curve at a lower level to compensate for lighter birth-weight and smaller ultimate adult size. Nor does it correspond to the growth-curve of Sahiwals, which have similar birth and adult sizes. Growth proceeds almost as rapidly in Holstein-Zebus as in Holsteins up to about 6 months of age. At this time a sharp break occurs and thereafter growth continues more slowly. Even if comparison is made with the growth-curve of Guernsey cattle [4], which have a similar adult size, the difference remains.

The break at about 7 months of age followed by slow and almost rectilinear growth is in contrast to the more rapid and regular curvilinear course of growth in temperate-zone breeds. Comparison with the growth-curve of Sahiwals, as representative of Zebu breeds, is less easy, at least from 4 months of age onwards. At this time the Holstein-Zebu heifers were weaned but the Sahiwal heifers studied by Sayer [5] were milk-fed

up to one year of age. It is possible that the sustained high growth found by Sayer is the result of prolonged milk feeding. The statement is often made that Zebu cattle mature more slowly than temperate-zone cattle, but we have been unable to find any record of growth studies under conditions of controlled feeding to compare with our own. But if this statement is correct, and bearing in mind the close similarity in the growth of Holstein-Zebus and Sahiwals up to the time the cross-bred calves were weaned, then the general picture of Holstein-Zebu growth must resemble that of Zebu cattle. It must be concluded that in spite of an ample provision of nutrients growth similar to that of temperate-zone breeds cannot be attained. As will be shown in Part III, sexual development is also delayed.

It is of particular interest to compare the growth records with the haematological picture we presented in Part I [1]. The break in the growth curve at about 7 months coincides with the point where a definite blood-picture has been established. During the first 6 months of life the haemoglobin level was higher than in the second 6 months, the transition to the lower level taking place during the period from 4 to 7 months. Similarly the red-blood-cell count fell to reach a relatively constant level at about 8 months of age. The concentration of haemoglobin in the blood was less than in either of the parent species. Essentially higher levels of haemoglobin were associated with rapid growth and lower levels with slow growth. A low level of haemoglobin might be expected to be detrimental to the proper functioning of the organism either by reducing the oxygen-supply to the tissues or by increasing the strain on the animal through promoting increased heart action, as is common in anaemia. No more can be said on the association between low haemoglobin levels with slow growth beyond drawing attention to the possible value of such blood tests as indicating future growth-performance in studies of the suitability of cattle for tropical conditions.

Considering now the growth-rates, as distinct from absolute growth, it is noteworthy that the rate of growth in Holstein-Zebu heifers during the first months of life is much higher than in Holsteins and approaches the growth-rate of Sahiwals. The period from 4 to 10 months is characterized by a sharp falling off in growth-rate to levels well below those of Holsteins. From 10 months to 2 years of age the rates are approximately the same in both breeds, i.e. the quantity of tissue laid down in successive intervals bears the same relation to that already accumulated. In future work it might be of interest to study the extent to which intervals of slow growth-rate (4–10 months in the present study) serve as a reliable indication that subsequent growth will be of the slow type as found in the present study. It is possible that such observations, combined with blood studies as described above, might accelerate tropical breeding programmes by giving a reliable indication at an early stage that subsequent performance will be inferior.

Whether the milking performance of the present heifers, their breeding efficiency and duration of life in the milking herd will be superior to the record of animals of comparable breeding but less adequately fed during early life, remains to be demonstrated. The results will be

presented in later communications after several lactations have been completed. The following partial records are of interest: two heifers have completed their first lactation with yields of 5,489 and 5,731 lb. for 328 days and 338 days respectively; one animal, still lactating, has completed 8 months with a yield of 4,247 lb.; five animals, still lactating, have completed from 5 to 6 months of lactation with yields of 1,664, 2,705, 3,020, 3,139, and 3,212 lb. These results compare favourably with those of three-quarter-bred Holstein-Zebus of the Government Stock Farm herd. Harrison [8], giving the results of a survey of this herd for the 10-year period just preceding the present investigation, reported the average milk production of three-quarter-bred cows to be 4,486 lb. per lactation.

As was stated earlier, one purpose of the present study was to determine the feed requirements for rearing tropical dairy stock in a manner comparable with temperate-zone dairying practice. The total amount of concentrates required to rear the cross-bred heifers from birth to first calving, which occurred at the average age of about 31 months, was approximately 3,800 lb. per head. This heavy consumption of concentrates is a consequence of the inadequacy of tropical roughage, particularly of the broad-leafed type, to provide nutrients for dairy cattle. Attention was drawn to the fact elsewhere [2, 3] that not only are fodder grasses, such as elephant-grass and Guatemala grass, of lower nutritive value than temperate-zone herbage, but also the quantities eaten by dairy cattle of the three-quarter-bred type are only about half the normal roughage consumption of stock on temperate-zone grazings. This low consumption of roughage was responsible for more of the need for concentrates than was the intrinsic low nutritive value of fodder grass.

The prevailing price of concentrates during the present study was about 5 dollars per 100 lb. The cost of concentrates used in rearing to first calving was thus 190 dollars per head. At prevailing retail prices the value of the milk consumed was about 108 dollars per head. Consequently the cost of rearing heifers was about 300 dollars per head, exclusive of overheads, labour, and roughage costs. (£1 sterling is equivalent to 4 dollars 80 cents, Trinidad.)

Summary

The nature of growth of three-quarter-bred Holstein-Zebu heifers from birth to 2 years of age was determined under controlled conditions of feeding. The relation between the growth of the cross-bred heifer and of Holsteins and Sahiwals, as representatives of the parent species, is discussed.

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THE ASH-CONTENT OF SOME GRASSES AND HERBS ON THE PALACE LEAS HAY PLOTS AT COCKLE PARK

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A CERTAIN amount is known about the major ash-constituents of most of the commoner grasses, and of a few of those miscellaneous herbs which are usually to be found in both grazing and meadow swards. Most of the research work has been due to Orr and his associates at the Rowett Research Institute [1, 2], and to Fagan and co-workers at Aberystwyth [3, 4, 5].

Evidence concerning the trace-element content of the pasture components generally is most scanty, but some data relating to the clovers, *P. pratense* and *P. trivialis*, are available in the American literature [6]. Thomas and Trinder [7] in this country have provided fairly complete data for certain of the moorland species.

It has been known for centuries that the major ash-constituents can be influenced to a very considerable degree by the initial character of the soil, or by the use of fertilizers. It is recorded by K. C. Beeson [6] that in 1682 Nehemiah Grew [8] was well aware of the effect of soils on the composition of the ash. De Saussure [9] possessed still more accurate information on this point. Comparatively recent data relating to the effect of soil conditions and fertilizers on both the major and trace mineral constituents of individual plants are plentiful. Much work has been done on the factors that influence uptake of manganese, boron, and magnesium by certain agricultural and horticultural crops, but the scope of this work is limited. Investigations into the trace-element contents of grasses have been largely concerned with copper, cobalt, molybdenum, and selenium. Moreover, this work has been directed towards the sward rather than to the species.

It should be recognized that when manurial treatment brings about major changes in the mineral efficiency of a sward, these changes reflect an altered botanical make-up to a greater extent than they do improvement or deterioration in the mineral efficiency of the individual species. Thus, two factors operate following the application of fertilizers: (1) the effect of those fertilizers on the balance of species, and (2) their effect on the mineral-content of the individual. The mineral efficiency of the sward as a whole will result from the interaction of the two.

One purpose of this work has been to study differences in the composition of the ash as between individual herbage plants. The other has been to determine the effects of varying manurial treatment on the ash of each individual.

Whether high mineral efficiency is of greater importance in young herbage, or in herbage at the hay-stage, is arguable. In view of the known poverty of most other winter foods in the trace elements [10], the importance of hay as a source would seem obvious.

Experimental

Material for the investigation to be described was obtained from the Palace Leas meadow-hay plots at Cockle Park. These plots were laid down in 1896 by the late Sir William Somerville for examining the effects of various manurial treatments on the yield and quality of old-land hay. As no major changes have been made since the plots were laid down, they have thus been under the same manurial treatments for 50 years. The cumulative effect of treatment on the swards is very evident, and there was reason to suppose that effects on the ash-constituents of individual species would be no less marked. The plots were therefore considered to be ideally suited to an investigation of the type contemplated. The soil of Palace Leas is a clay loam varying from 8 to 15 in. in depth, and overlying a stiff boulder-clay subsoil. Although there are 16 plots, the present investigation has been confined to the 6 referred to below.

Plot 2 has received farmyard manure at the rate of 8 tons per acre per annum. Plot 6 is the control. Plots 7, 8, and 9 have received, annually, 150 lb. sulphate of ammonia, 300 lb. basic slag, and 100 lb. muriate of potash, respectively. A complete fertilizer dressing comprising the same weights of sulphate of ammonia, basic slag, and muriate of potash as have been used on the 3 foregoing plots has been applied every year to plot 13. These treatments are described in greater detail elsewhere [11].

It was felt that some data concerning the soil of the experimental plots might provide auxiliary information on the effect of treatments. These data, which had recently become available as a result of other work done by the authors, are tabulated below:

TABLE 1. *Analysis of Air-dry Soil*

Plots	*pH*	*Avail.* P_2O_5, %	*Avail.* K_2O, %	*Exch. CaO*, %
2	5·33	0·015	0·004	0·307
6	4·82	0·006	0·003	0·218
7	4·15	0·007	0·004	0·171
8	5·34	0·012	0·005	0·359
9	4·82	0·006	0·015	0·227
13	5·10	0·014	0·004	0·281

Selected for investigation were those grasses and herbs which were most abundant on the plots, and one or two others, the frequency of which was obviously affected by manurial treatment. These comprised the following species: crested dogstail (*Cynosurus cristatus*), Yorkshire fog (*Holcus lanatus*), red fescue (*Festuca rubra* spp.), ribgrass (*Plantago lanceolata*), buttercup (*Ranunculus* spp.), sheep's sorrel (*Rumex acetosella*), and yellow rattle (*Rhinanthus Crista-galli*). Sampling was begun early in June, 3 weeks before mowing. This was the latest time at which the work could be done without appreciable damage to the standing grass. A total period of 12 days was required, but each single species was sampled in the course of one working day. Two separate samples of

H. lanatus were obtained, this species being the first sampled and the last; the object of this was to make a rough assessment of the maximum change in ash-constitution which was likely to occur during the sampling period. No cutting instruments were used, the plants being plucked with the fingers at about 1½ in. above ground-level; these precautions were considered adequate to prevent soil or other contamination. When a species was thin on the ground, as was the case with *R. acetosella*, it was found necessary to cover the plots in their entireties. Representative samples of such species as *R. Crista-galli* were obtained by working across both diagonals. As the Palace Leas plots are narrow, every precaution was taken to avoid edge-effect.

Samples were packed into paper bags for conveyance to the laboratory, where they were picked over to ensure the absence of any extraneous material. Thereafter, they were dried for an arbitrary period of 24 hrs. at 55° C., and ground in a Christie-Norris mill using a $\frac{1}{32}$-in. sieve. It is realized that the last procedure is open to criticism where material is to be used for trace-element work. No practicable alternative was, however, available and, as the results were required primarily for comparative purposes, grinding in an ordinary mill was considered to be justifiable.

The majority of the analytical methods used in this investigation are as recommended by Godden [12], though in certain cases small modifications in procedure were made, and in others the substitution of the recommended method by one of more recent origin, or of more convenient form, was thought desirable.

Discussion

The value, as sources of mineral matter, of the plants studied is discussed below:

Plantago lanceolata (Ribgrass). The usefulness of this herb, more especially as a component of meadow swards, has been recognized by practical men for very many years. Fagan and Watkins [5] have shown that it is an outstandingly good source of at least two of the major elements, containing more than 2 per cent. of both calcium and chlorine; it is, moreover, a very useful source of phosphorus and potassium.

The results of the present work confirm the finding that it is an extremely good source of calcium, and contains very useful amounts of phosphorus. Neither potassium nor chlorine was present in amounts as great as those found by Fagan (q.v.). More sodium was present than in any other plant studied, but the amounts of magnesium were small. As a source of the minor elements generally, *P. lanceolata* was shown to be highly efficient containing, in particular, relatively large amounts of copper and cobalt; only in respect of manganese was it poor.

Ranunculus spp. (Buttercup). Opinions seem still to be divided concerning the wholesomeness of *Ranunculus* spp., and the extent to which they are eaten by grazing stock. The poisonous properties attributed to one or two of them are lost on drying, and Long [13] and other writers maintain that, as constituents of hay at least, these plants are of nutritional value and are readily eaten. Fagan and Watkins [5] have examined one sample of this species, consisting largely of *R. repens*, and found it

Results

TABLE 2. *Ash-constituents of Grasses and Herbs under Different Manurial Treatments. (Results calculated to Dry-matter Basis)*

Species	Plot	Silica-free ash %	Calcium (CaO) %	Phosphorus (P_2O_5) %	Potassium (K_2O) %	Magnesium (MgO) %	Chlorine (Cl) %	Sodium (Na_2O) %	Sulphur		Iron (Fe) p.p.m.	Manganese (Mn) p.p.m.	Copper (Cu) p.p.m.	Cobalt (Co) p.p.m.
									Inorganic (S) %	Organic (S) %				
Plantago lanceolata	2	10·00	2·41	0·80	1·93	0·16	0·43	1·16	0·31	0·15	178	75	16·1	0·22
	6	8·20	2·23	0·48	1·56	0·15	0·40	1·04	0·30	0·16	156	121	16·0	0·29
	7	8·58*	2·12*	0·65*	1·53*	0·17*	0·37*	0·97*	0·27*	0·16*	174*	81*	15·2*	0·26*
	8	8·37	2·27	0·95	1·54	0·15	0·45	1·03	0·26	0·13	122	50	15·7	0·22
	9	9·25	1·88	0·56	2·50	0·14	0·74	0·49	0·27	0·14	138	105	16·1	0·25
	13	8·97*	2·23*	0·80*	1·84*	0·14*	0·75*	0·96*	0·29*	0·13*	139*	119*	16·2*	0·21*
	Mean	8·89	2·19	0·71	1·82	0·15	0·52	0·94	0·28	0·15	151	92	15·9	0·24
Ranunculus spp.	2	8·20	1·48	0·95	3·10	0·34	0·25	0·26	0·08	0·15	56	77	17·5	0·25
	6	6·89	1·43	0·60	2·46	0·34	0·20	0·21	0·06	0·15	170	134	13·5	0·26
	7	7·35	1·39	0·74	2·52	0·36	0·24	0·32	0·05	0·17	140	98	16·0	0·26
	8	7·30	1·48	0·90	2·60	0·37	0·33	0·33	0·05	0·18	92	82	17·7	0·22
	9	7·85	1·40	0·64	3·22	0·30	0·45	0·27	0·07	0·12	125	149	16·8	0·24
	13	8·25	1·45	0·93	2·98	0·36	0·56	0·33	0·06	0·17	117	122	17·9	0·24
	Mean	7·64	1·44	0·80	2·81	0·35	0·34	0·29	0·06	0·16	117	110	16·6	0·25
Rumex acetosella	2	9·74	0·71	1·37	4·82	0·26	1·25	0·27	0·04	0·26	139	135	11·0	0·22
	6	9·19	0·63	1·02	4·28	0·27	1·24	0·34	0·05	0·25	144	299	14·2	0·27
	7	8·33	0·70	1·09	3·69	0·28	1·21	0·42	0·09	0·22	163	201	11·7	0·22
	8	9·65	0·92	1·40	4·12	0·29	0·99	0·33	0·10	0·12	137	214	5·4	0·12
	9	10·56	0·69	1·17	5·12	0·24	1·65	0·24	0·07	0·15	191	372	8·5	0·22
	13	10·90	0·97	1·37	4·53	0·27	1·45	0·32	0·14	0·15	196	502	14·2	0·20
	Mean	9·73	0·77	1·24	4·43	0·27	1·30	0·32	0·08	0·19	162	287	10·8	0·21
Rhinanthus Crista-galli	2	12·19	1·88	2·12	3·74	0·73	1·40	0·21	0·48	0·18	101	345	17·9	..
	6	11·08	1·70	1·44	3·40	0·66	1·30	0·45	0·35	0·17	128	413	14·2	..
	7	10·71*	1·83*	1·59*	3·32*	0·70*	1·21*	0·43*	0·37*	0·17*	158*	479*	12·4*	..
	8	11·09	2·28	1·87	3·26	0·82	1·37	0·49	0·37	0·14	160	301	10·9	..
	9	10·39	1·58	0·97	4·25	0·51	1·14	0·46	0·33	0·15	141	897	12·1	..
	13	10·59	2·05	1·86	3·72	0·66	1·41	0·37	0·39	0·13	125	513	10·3	..
	Mean	11·01	1·89	1·64	3·62	0·68	1·31	0·40	0·38	0·16	136	491	13·0	..

	13	10·59	2·05	1·86	3·72	0·66	1·41	0·37	0·39	0·13	125	513	10·3	..
	Mean	11·01	1·89	1·64	3·62	0·68	1·31	0·40	0·38	0·16	136	491	13·0	..
Cynosurus cristatus	2	4·16	0·26	0·67	2·37	0·22	0·76	0·28	0·08	0·09	47	95	5·9	0·31
	6	3·21	0·21	0·37	1·42	0·18	0·56	0·32	0·06	0·13	61	132	4·4	0·23
	7	3·48	0·20	0·61	1·33	0·17	0·56	0·41	0·03	0·13	76	96	4·9	0·16
	8	3·47	0·28	0·53	1·71	0·20	0·66	0·31	0·07	0·07	69	119	6·9	0·12
	9	3·88*	0·11*	0·33*	2·17*	0·14*	0·81*	0·25*	0·05*	0·09*	61*	257*	4·8*	0·20*
	13	3·78	0·24	0·54	1·58	0·15	0·86	0·41	0·07	0·10	53	139	6·4	0·13
	Mean	3·66	0·22	0·51	1·76	0·18	0·70	0·33	0·06	0·10	61	140	5·6	0·19
Holcus lanatus (Cut 1)	2	6·81	0·35	0·93	3·39	0·27	0·99	0·17	0·11	0·13	175	229	11·5	0·17
	6	5·38	0·35	0·61	2·75	0·24	0·90	0·18	0·07	0·13	42	389	7·9	0·19
	7	5·76	0·30	0·65	2·84	0·31	0·94	0·31	0·08	0·14	68	380	6·9	0·14
	8	5·57	0·40	0·92	2·95	0·19	1·08	0·29	0·07	0·14	47	174	8·0	0·14
	9	6·11	0·34	0·70	3·18	0·25	1·18	0·16	0·07	0·14	62	479	6·1	0·14
	13	5·63	0·42	0·85	2·78	0·24	1·21	0·23	0·07	0·14	76	287	8·5	0·14
	Mean	5·88	0·36	0·78	2·98	0·25	1·05	0·22	0·08	0·14	78	323	8·2	0·15
Holcus lanatus (Cut 2)	2	6·10	0·32	0·71	2·29	0·19	0·80	0·18	0·08	0·10	66	189	12·4	0·17
	6	5·10	0·30	0·47	1·96	0·23	0·75	0·24	0·07	0·10	67	437	8·9	0·19
	7	5·80	0·25	0·56	2·15	0·23	0·82	0·19	0·06	0·12	75	383	8·4	0·26
	8	4·35	0·29	0·66	1·96	0·22	0·75	0·27	0·10	0·10	71	425	8·7	0·17
	9	5·57	0·27	0·54	2·22	0·21	0·84	0·30	0·10	0·11	79	380	8·9	0·24
	13	5·07	0·35	0·68	2·02	0·22	0·93	0·31	0·12	0·10	62	370	9·4	0·14
	Mean	5·33	0·30	0·60	2·10	0·22	0·82	0·25	0·09	0·11	70	364	9·5	0·20
Festuca rubra spp.	2	3·73	0·24	0·44	1·68	0·15	0·48	0·60	0·08	0·04	181	166	5·0	0·17
	6	3·08	0·18	0·27	1·44	0·10	0·38	0·65	0·08	0·01	105	178	3·6	0·23
	7	3·20	0·18	0·33	1·34	0·16	0·36	0·50	0·06	0·04	241	184	3·5	0·24
	8	3·12	0·23	0·42	1·56	0·12	0·42	0·56	0·06	0·04	115	175	3·6	0·18
	9	3·52	0·21	0·31	1·72	0·15	0·54	0·47	0·07	0·05	104	305	3·8	0·21
	13	3·69	0·23	0·48	1·66	0·11	0·55	0·51	0·09	0·03	57	172	4·5	0·16
	Mean	3·39	0·21	0·38	1·57	0·13	0·46	0·55	0·07	0·04	134	197	4·0	0·20
Standard error of species of order of		±0·22	±0·045	±0·055	±0·090	±0·018	±0·045	±0·040	±0·015	±0·012	±20·0	±40·0	±0·75	±0·015

* Calculated probable values

to contain relatively large amounts of calcium and potassium, and to be a very useful source of phosphorus and chlorine. Incidentally, the crude-protein content is excellent, and the fibre low.

The useful character of *Ranunculus* spp. as sources of calcium and phosphorus has been fully confirmed, but they proved to contain much less chlorine and substantially more potassium than did the sample referred to above; they were rich in cobalt and copper but notably poor in manganese and sodium.

Rumex acetosella (Sheep's sorrel). In this case also there is uncertainty concerning the value as a food for livestock. Lander [14] has stated that some species of the order Polygonaceae are held to be responsible for poisoning, but admits the existence of doubt. The plants, including *R. acetosella*, are known to contain oxalates, but most allegations of damage resulting from their consumption are based upon unsubstantial evidence. Brenchley [15] has classed *R. acetosella* as a plant possessing some feeding-value, but one which must be regarded as a weed if present in too large quantity; and Cockayne's [16] findings seem to bear out her assessment. The work of Fagan and Watkins indicated that *R. acetosella* is an exceptionally good source of both calcium and phosphorus. The crude-protein content is very good and the fibre low.

The authors' results conform fairly well to those referred to above in respect of potassium and phosphorus, but show a notably higher chlorine-content, and distinctly less calcium. *R. acetosella* proved to contain large amounts of iron, but was not more than a moderately useful source of the trace elements. Apart from its high content of potassium and iron, it cannot be regarded as a herb of outstanding mineral efficiency.

Rhinanthus Crista-galli (Yellow rattle) is generally regarded as a highly undesirable weed of meadows, and there is little doubt that good grounds exist for this view. It is said to be distasteful to stock whether fresh or in hay; in general, however, stock will not encounter it in the fresh condition, and when they receive it in hay are obliged to eat it whether they relish it or not. It is admittedly not difficult to eradicate *R. Crista-galli* from meadow-land; nevertheless, its occurrence is widespread and, under these circumstances, it may be well to consider what effect its inclusion in hay may have on the nutritive value of the whole. Fagan has shown this plant to contain outstandingly high proportions of calcium and phosphorus, and incidentally to be rich in crude protein. He remarks that although the plant is not looked upon with favour, it does seem possible that it may make some contribution to productivity.

The samples examined by us provide ample confirmation of Fagan's results, and show, moreover, that the plant contains large amounts of every other ash-constituent determined. It is, in particular, a remarkably good source of copper, manganese, sodium, and magnesium. Unfortunately, the analytical sample was not sufficiently large to allow of a cobalt estimation. In brief, *R. Crista-galli*, in so far as it can be judged on the ordinary analytical data, is the most highly mineral efficient herbage plant that has so far been examined. Hence, whilst it may be regarded as an undesirable component of a meadow sward, one cannot conclude that it is necessarily a worthless constituent of hay.

Cynosurus cristatus (Crested dogstail) is generally recognized to be a useful grass in any circumstances, but is probably of maximum value under conditions other than the best. It flourishes on most soils, and withstands adverse conditions very well. Its palatability is indubitably high. Being essentially a bottom grass, it is of little or no value in meadows, but has very often been used in mixtures for permanent leys.

Examination of the ash of this grass shows it to be a distinctly poor source of minerals. Moderate amounts only of phosphorus are present, and the remaining major elements are relatively deficient. The trace elements are in no better case, copper, in particular, being very low. *C. cristatus* must therefore be regarded as a poor source of minerals and, if present in large amount, as likely to have an adverse effect on the mineral efficiency of the sward as a whole.

Holcus lanatus (Yorkshire fog). Whether this grass is invariably so worthless as is commonly supposed may perhaps be doubted. It is a fact that considerable proportions of it do occur in some of the best feeding pastures. Most writers maintain that the hairiness of *H. lanatus* detracts from its palatability to such an extent that stock will seldom touch it. It is therefore of interest that Milton [17], although he observed some variation with conditions, found to his surprise that stock were not always averse to it. Fagan and Milton [4] showed that *H. lanatus* contained calcium and phosphorus in amounts which, although rather smaller than in *L. multiflorum*, were comparable to those found in many other of the so-called better grasses.

The phosphorus-content of the Palace Leas samples agrees closely with that found by Fagan, but the calcium is appreciably lower. Most of the other ash-constituents determined were present in respectable amount, only magnesium and cobalt being low by any standard. Whatever the other attributes of *H. lanatus* may be, it would appear that, if and when eaten, it is capable of supplying useful amounts of nearly all of the more important ash-constituents.

Festuca rubra spp. (Red fescue), the best of the fescues, is a bottom grass fairly widely distributed. It is persistent, and relatively productive under the conditions best suited to it, i.e. on poor, rather dry soils. Its palatability is distinctly higher than might have been expected. The investigations of Davies [18] show it to possess an acceptability of 60 per cent. of that of *L. perenne*. Van Itallie [19] has shown *F. rubra* to be a poor source of calcium, magnesium, potassium, and sodium. Fagan's results [3], which probably apply to *F. ovina* rather than to *F. rubra*, show the fine-leaved fescues to be low in both calcium and phosphorus.

Our results show *F. rubra* to be one of the poorest sources of both major and trace elements. Only iron and manganese provide exceptions, the former of these being present in comparatively large amount. By any standards, *F. rubra* spp. must be considered to be of little value as a source of minerals. It is probably not unreasonable to suggest that the presence of this grass in any considerable amount would be likely to render a sward, whether meadow or pasture, incapable of meeting the normal mineral requirements of livestock.

A majority of the species contained a higher phosphorus-content

where farmyard manure had been applied than elsewhere. This effect was unexpected; on the assumption that F.Y.M. contains 0·25 per cent. of phosphorus (as P_2O_5), the 8 tons applied annually would supply 45 lb. of phosphorus per acre as against 50 lb. applied to Plots 8 and 13 as basic slag. In every case the potassium-content on Plot 2 is markedly higher than on the untreated plot, but most species show a slightly lower content than on Plot 9. The first of these results was to be expected; the reason for the second is perhaps not immediately obvious. If the F.Y.M. contained 0·5 per cent. of potassium (as K_2O) then the annual dressing would supply about 90 lb. as against 50 lb. on Plot 9. It may be noted that the mean yield of hay over 35 years has been 16 cwt. per acre on the latter plot, as against 41·5 cwt. on the former. The total uptake of potassium is therefore very much higher than on Plot 9. In general, the copper-content is high on Plot 2, and in every case except one (*R. acetosella*) it is higher than on Plot 6. These results can be explained only on the assumption that F.Y.M. contains appreciable amounts of copper; there is, in fact, evidence that it does [20, 21, 22]. The generally low content of manganese under this treatment coincides with the accepted view that uptake is positively related to acidity, and negatively to alkalinity and high organic matter. All species except *C. cristatus* contain less cobalt than on Plot 6.

The effect of the application of sulphate of ammonia has been to give all species a higher phosphorus-content than on Plot 6. This reflects a slightly higher available-phosphate content of the soil (cf. Table 2). Roy [23] obtained similar effects on soil of the same class from the adjacent Tree Field. There is much evidence that nitrogenous fertilizers positively affect phosphorus-uptake. In general, the iron-content of plants on Plot 7 is high, and it seems obvious that this is a reaction effect. All but two species show lower manganese than on Plot 6. This result is somewhat unexpected in view of the very low pH of the plot. It is noteworthy that whilst the exchangeable calcium in the soil of this plot has been markedly reduced—a similar effect has been observed by Crowther [24] and others—there has been no appreciable decrease in the calcium-content of the sward components: a result that is not in accord with the findings of other workers [2].

The phosphorus-content of all species under treatment with basic slag is fairly high, and there are indications of increased calcium, although such increases are not large. The foregoing results are such as had been expected. That basic slag so affects the phosphorus- and calcium-contents of pastures has been known for a long time, Paturel [25] having remarked on it nearly 40 years ago. Both iron and manganese are rather low in a large majority of species under this treatment, and a similarly depressing effect is to be observed on cobalt. Relatively high pH is probably responsible for the smaller uptake of iron and manganese, but we cannot explain the effect on cobalt. Thomas, Escritt, and Trinder [26] observed similar effects on manganese and iron on those Tree Field plots which had received basic slag, but their figures for cobalt show less consistency.

The effect of treatment with muriate of potash has been to depress

the calcium in most species. This is in accord with the findings of others [27]. The potassium-content of all species is high, the figures being comparable with those obtained under treatment with F.Y.M., and higher than where a complete fertilizer containing the same weight of muriate of potash has been applied. No explanation of this can be offered. Sodium-contents show a general tendency to depression under this treatment. Stahl-Schröder [28] and others have shown that an inverse relationship exists between potassium and sodium. Most species under this treatment are high in manganese, and the iron-content is generally low. Chlorine-content is high as compared with Plot 6, and is indeed higher here than on any plot other than that receiving a complete dressing of artificial fertilizer. It is common experience that chlorine-uptake reflects application, as it appears to have done in this instance. Knoblauch and Odland [29] and other workers have stated that an increased supply of potassium to the soil reduces the magnesium-uptake by the plant. A majority of species on Plot 9 manifest this effect.

The expected increase in phosphorus-content from application of a phosphatic fertilizer has been shown by all species under complete fertilizer treatment; phosphorus-contents are, in general, comparable to those on Plots 2 and 8. In all but one species the chlorine-content under this treatment is slightly higher than on Plot 9, although the weights of chloride applied to these plots were identical. Some of the species show their lowest cobalt-contents on this plot, and the effect of the treatment has been generally depressive of cobalt. It seems fairly obvious that this effect, which has already been observed on Plot 8, and to some extent on Plot 7, is due mainly to the basic slag contained in the mixture and, in part, to the sulphate of ammonia.

The investigation described has provided results which fully confirm the findings of earlier workers relative to the efficiency of the broad-leaved species as sources of such major elements as calcium and phosphorus. These results, moreover, indicate that they are markedly superior to the grasses in their content of the trace elements. Only a few of the herbs have been studied, and it is conceivable that there are others which may share the outstanding qualities of *P. lanceolata* as a source of minerals for farm livestock. As Stapledon [30] has recently pointed out, much remains to be learned. Fuller information on the trace-element content of the grasses generally, and in particular of the so-called 'better' species, is required. Similar data relating to all herbs that occur to any appreciable extent in grassland should be available. Nevertheless, the existing evidence, slight though it be, is sufficient to justify the use of herb strips, and probably warrants serious consideration of the inclusion of at least certain herbs in permanent leys for grazing or mowing.

One outstanding feature of these results has been the effect of conventional manurial treatments on the ash-content of the sward components. Basic slag alone, or in a complete mixture such as is frequently applied to meadow-land, increases the major mineral elements, but depresses trace elements. Natural manures, e.g. F.Y.M., are effective in increasing the amounts of one or two trace elements only. The idea that natural manures supply lavish amounts of trace elements to the growing crop

has found no support in this case. As changes in manurial practice, capable of increasing the all-round efficiency of the sward for trace-elements, are in the highest degree improbable, it would seem that the only practicable means of doing so, is to encourage deliberately individual species known to contain relatively large amounts of these elements.

Summary

The ash-constituents—including trace elements—of three grasses and four miscellaneous herbs growing on meadow hay plots at Cockle Park have been examined. In addition to differences between species, the effects of varying manurial treatment have been determined.

In general, the broad-leaved species were more highly mineral efficient than the grasses examined. Two herbs were shown to be outstandingly good sources of mineral matter; one of these, viz. *R. Crista-galli*, is commonly regarded as a particularly obnoxious weed; the other, *P. lanceolata*, is recognized as a herbage component of at least limited usefulness.

Manurial treatment had marked effects on the ash-constitution of individual species. Basic slag depressed the trace-element content.

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SILAGE-MAKING IN THE NETHERLANDS

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In addition to haymaking and crop-drying by artificial heat, silage-making also plays a prominent part in the food supply of Dutch cattle. Many methods of ensiling have been advocated in recent years, and most of them have been studied at the Hoorn Experimental Station. In this article the experimental work of the Bacteriological and Physiological Sections is reviewed, and the rationale of the principles involved in most of the ensiling methods reviewed is derived from the publications of the Bacteriological Section [1, 2, 3, 4], which include studies of the influence of silage-feeding on cheese-making.

The Warm-fermentation Process

Following two small experiments by Boekhout with grass [5], and de Vries [6] with potato-tops, in 1926 Brouwer [7] carried out a feeding-trial with two groups, each of 13 high-milking Friesian cows, fed on hay and silage respectively, both fodders being made from the same grass. The silage was prepared by the Dutch warm-fermentation method. A slightly withered grass was packed in loose layers in a clamp, and covered with soil after the top layer had been warmed through; the temperature rose to 45–70° C. No lactic or butyric acid is present in well-made hot silage, but experience has shown the difficulty of preparing a good sweet silage by this method: the packed material is not homogeneous, and the high temperature reduces the digestibility of the protein. Brouwer found that 7·21 kg. of dry matter in his silage produced nearly the same quantity of milk and butter-fat as 7·55 kg. of dry matter in his well-cured hay. In 1927 [8] he did a feeding-trial with hay and Dutch silage; the weather was bad for haymaking and 6·07 kg. of dry matter in the silage gave more milk and fat than 7·28 kg. in the hay.

In later trials [9] made at this station the fatal effect of high temperature on protein digestibility was confirmed. The highest temperature in a wooden silo was 76° C. and that in a clamp 81° C.; the products both contained much butyric acid and the digestibility coefficients of crude protein fell from 74 to 34, and from 74 to 17·5, respectively. The digestibility of the true protein fell even more. Though the temperatures were too high the trials clearly demonstrated the disadvantages of the Dutch warm-fermentation process.

The Cold-fermentation Process

The principle of this process is to keep down the temperature by steady pressing of wet material, so reducing the enclosed air and allowing anaerobic and facultative-anaerobic bacteria to flourish and produce organic acids or putrefaction. In the presence of carbohydrates from the cell-sap the lactic-acid bacteria multiply quickly, reduce the pH,

and eliminate the carbohydrates. If the lactic fermentation ceases before the pH is sufficiently reduced butyric-acid bacteria (*Clostridium tyrobutyricum*) come into play, reduce the acidity, and allow anaerobic putrefaction to ensue. All cold-fermentation methods aim at steering the biological processes into the right channels.

Molasses.—The addition of sugar or molasses causes a rapid lactic-acid fermentation and a quick fall in pH. If too little sugar is used acidity remains too low, butyric-acid bacteria get their chance, and an 'unstable' silage results. The border-line between stability and instability lies around pH 4·2. Experiments were made in 1934, 1936, 1937, 1938 [10, 11, 12] to find out the minimum percentage of sugar needed to obtain a good silage from autumn grass. The average results are given in Table 1. It was concluded that at least 2 per cent. of sugar (4 per cent. molasses) must be used. Unless the farmer possesses a water-tight silo he should add 6 per cent. of molasses.

TABLE 1. *Effects on Quality of Silage of adding Varying Amounts of Sugar*

	In a water-tight concrete silo			*In a drained wooden silo*
Sugar added, % .	3·0	2·0	1·0	1·0
pH . . .	3·94	3·97	4·49	4·40
Butyric acid, % .	0·0	0·15	0·92	0·71
Lactic acid, % .	2·10	1·82	0·82	1·09
Ammonia-N as % of sol. total-N . .	13·3	17·7	38·9	33·3
Loss of protein, % .	17·1	22·5	32·1	31·6

Mineral acid.—The A.I.V. method uses a mixture of hydrochloric and sulphuric acids; the East Prussian (Defu) method either hydrochloric acid alone or mixed with phosphoric acid plus a little sugar. Both these methods have been fully investigated [11, 13, 14, 15, 16, 17, 18], using drained wooden silos, and the averaged comparative results are given in Table 2. In both methods a little butyric acid (in the top layer only),

TABLE 2. *Comparison of the Defu and A.I.V. Methods*

	Defu method		*A.I.V.-method*		
pH	3·7	3·57	3·53	3·20	3·28
Acetic acid, % . .	0·32	0·35	0·27	0·15	0·19
Butyric acid, % . .	0·03	0·13	0·07	0·03	0·04
Lactic acid, % . .	1·02	1·30	0·91	0·51	0·56
Loss of protein, % .	20·2	17·5	12·8	14·8	14·5

and acetic and lactic acids were found. There was a correlation not only between pH and loss of protein, but also between pH and the amount of organic acid present, thus confirming the fact that the bacterial processes are strongly influenced by the acidity of the substrate. At pH 4 lactic fermentation is still possible; from pH 3 fermentation sinks gradually to zero. As in the A.I.V. process the acidity prescribed is between 3 and

4, it is incorrect to state that this process demands an acidity at which bacteria are unable to live, rather that bacterial life is greatly reduced.

It was also found that the use of mineral acids improved the starch equivalent by 10 per cent. and the digestible crude protein by about 50 per cent. as compared with the Dutch clamp method. Therefore, solely from the point of view of nutrient losses, the mineral-acid methods are best. Moreover, they yield a silage that is readily eaten by cattle, and produce no bad after-effects.

Investigation of the physiological effects of silage made with mineral acid [19, 20] showed that with pH 3–4 and no base added the acidity of the urine decreased, and the ammonia percentage increased. Large quantities of these silages, or moderate quantities of very acid silage, cause acidosis, the symptoms including blood-changes, bad appetite, bristling hairs, and emaciation; but these symptoms were not observed when the cows received sufficient sodium bicarbonate. Brouwer [21] found that feeding an excess of bases had no adverse effect on the acid-base equilibrium or on the health and productivity of dairy cows. Some years ago Møllgaard and Thorbeck concluded that in some cases sodium carbonate does decrease digestibility; therefore digestibility trials were undertaken [22] with two mineral-acid silages of good quality fed to two sets of three wethers, two animals in each set receiving bicarbonate and the third no bicarbonate. The results showed no adverse effect on digestibility.

Most farmers do not like handling strong acid, hence the marketing of two preparations, 'Dusarit' and 'Biosil', which contain sulphuric acid absorbed in charcoal and can therefore be applied in powder form. Our trials [11] showed, however, that Biosil containing 60 per cent. acid was very hygroscopic and therefore inconvenient in use. The Dusarit contained only 20 per cent. acid and was not hygroscopic. Neither of these preparations has made headway in the Netherlands.

Formic acid.—In the years immediately before the Second World War formic acid, under the name of 'Formasil', was available for treating green fodder, and the claim was made that much less of it was required than of A.I.V.-acid. Our experiments [23, 24] with water-tight concrete and with wooden silos, varying quantities of formic acid, and corresponding quantities of A.I.V.-acid, showed that formic acid has no acidifying effect on metabolism. Physiologically, then, formic acid is preferable to mineral acid, but our experiments and those of the Central Institute of Agricultural Investigations (C.I.L.O. in Dutch) at Wageningen [25] disclosed no indication that formic acid has any specific ensiling effect. Consequently, and in complete disaccord with the German claim, it is necessary to use just as much of it as of A.I.V.-acid; and it costs much more.

Whey and skim milk.—In 1935 the possibility of using whey and skim milk attracted great attention in the Netherlands and many experiments were undertaken to determine their value [3, 11, 18]; also a large number of samples made with them in different localities were examined [4, 26]. Theoretically their value might be due to (*a*) the acid-content, (*b*) the lactic-acid bacteria in them, and (*c*) the sugar-content.

(*a*) The amount of acid involved was found to be almost negligible. (*b*) Acid whey contains only lactic streptococci, which produce little acid, and there are plenty of acid-forming cocci on grass. The few rod-shaped lactic-acid bacteria in acid whey are practically insignificant; and consequently (*c*) the efficacy of whey and skim milk depends on the sugar they contain. But whey contains only about 5 per cent. of lactose, and to supplement it by adding 3 per cent. of sugar, a minimum of 60 litres of whey would have to be added for each 100 kg. of grass; this is out of the question because the whey would first have to be concentrated by evaporation. The quality of the silage made with 10 and 15 per cent. whey, as well as that produced on farms, was very poor, but in 1946 we succeeded in making a good sample by adding 4 per cent. of whey powder. The content of butyric acid was low (0·3 per cent.), the percentage of lactic acid was high (about 1·8 per cent.), pH was 4·1, and there was little breakdown of protein. We concluded that whey may be profitably used only for diluting in the molasses method.

There remain to be discussed three methods that are still in the experimental stage.

Hardeland's method.—Sugar-beet and potatoes are crushed to a pulp in a special (Eirich) mill, and then blown into the silo with the chopped material to be ensiled. The underlying idea is that the carbohydrates of the beet and potatoes will stimulate lactic-acid fermentation. Bacteriologically beets are better than potatoes because their sugar forms a good substrate for lactic-acid bacteria. Ensiling with crushed beets is essentially the same as ensiling with molasses, but sufficient must be used to get the sugar up to 2–3 per cent. Raw potato starch is not a good medium for lactic-acid bacteria. In 1946 we ensiled grass with 4 per cent. of potato starch [27], but the product was bad: pH was 5·0, butyric acid 1·3 per cent., lactic acid only 0·2 per cent., and 54 per cent. of the total nitrogen in the sap was present as ammonia. The conserving effect of crushed potatoes is, therefore, still in doubt.

Solid carbon dioxide.—The object of using solidified carbon dioxide is to expel air and inhibit respiration of the living plant-cells; also, of course, to lower the temperature. Our recent experiments [27] showed that the addition of 1 per cent. of it reduced the temperature only by 3° C., and therefore had little influence on bacterial growth. We do not yet know if this addition favourably affects the quality of the silage. If in addition to its undoubted acidifying effect, it reduces respiration losses and leaves more carbohydrates available for lactic-acid bacteria, then it should be useful; but how great its conservation effect is remains to be proved.

'*Vitasan*'.—This is a mixture of salts, of which phosphates, ammonium compounds, and an oxidizing agent are claimed to be essential; the phosphates stimulate the growth of lactic-acid bacteria; the oxidizing agent, e.g. potassium bromate, prevents the breakdown of proteins by oxidizing glutathione, which is the activator of proteolytic enzymes. The presence of trace elements in Vitasan, it is claimed, should influence the bacterial flora, reduce protein losses, and inhibit the formation of butyric acid. Against these claims it is contended that, in general,

grass already contains enough phosphate and trace elements to promote lactic fermentation. It is also claimed that Vitasan would exert a buffer effect, the pH would not rise, and there should be no putrefaction. In support of their claims the proprietors of Vitasan have published good results of their trials, but the C.I.L.O. at Wageningen have obtained entirely negative results [28], and its findings have been corroborated by farmers.

We tested these rival claims at Hoorn in the autumn of 1946 [27], using grass and two small concrete silos, with the following results (Table 3):

TABLE 3. *Results of an Ensiling Experiment with 'Vitasan'*

	pH	*Acetic acid,* %	*Butyric acid,* %	*Lactic acid,* %	*NH_3-N as % of sol. total-N*
			Silo I Controls		
Upper half	5·10	0·88	0·97	0·52	63·2
Lower half	5·00	0·86	0·96	0·62	55·6
			Silo II (Vitasan)		
Upper half	5·10	0·72	0·85	0·59	51·8
Lower half	5·03	0·77	0·55	0·66	42·4

The loss of digestible protein was 67·4 per cent. in the Vitasan silage and 74·5 per cent. in the control. Although the Vitasan supplement had little effect on the formation of lactic acid, it slightly reduced that of butyric acid and the breakdown of protein. Nevertheless, the quality of the silage was bad; these experiments were continued in the autumn of 1947.

'*Drowning*' *method.*—The first requirement for a good silage is that the pH falls below 4·2, but our researches have shown that in such silage there is always some butyric-acid fermentation, which makes it suspect for cheese-making. The cause of this happening is the layer-structure of the silage due to discontinuous addition of mineral acid or molasses; penetration to the inner layers is insufficient, and there the pH is not sufficiently lowered. Except perhaps in the Hardeland method, it is technically impossible to secure homogeneity in the silage by any of the processes now practised. The only way to ensure homogeneity is to see that the added substance diffuses rapidly into the inner layers during the first few days after filling the silo. Since diffusion depends on the juice-content during the filling of the water-tight silo, sufficient liquid—diluted molasses or mineral acid—must be added to 'drown' the material for a few days. We tested this method in 1936 [29], using 3,300 kg. of fresh grass and 500 litres of a 25 per cent. sugar solution, equivalent to 15 litres of liquid + 3·5 kg. of sugar per 100 kg. of grass. Except at the top where the liquid had not 'drowned' the fodder, the silage obtained was free from butyric acid; it contained only a few bacteria of the type *Cl. saccharobutyricum*, which do not ferment lactic acid. In this method the juice may be removed after the silage has ripened or before the silo is opened; it may be fed to cattle, so reducing feed-losses to a minimum.

Summary

1. Warm fermentation as practised in the Dutch clamp process is inferior to cold fermentation regulated by addition of acid or sugar.

2. In the molasses method at least 2 per cent. of added sugar (4 per cent. of molasses) is necessary.

3. Since 1932 the mineral-acid process has been increasingly used in Holland, but excess acid should be neutralized.

4. Formic acid does not cause acidosis; it has no specific ensiling effect and its use is uneconomic in the Netherlands.

5. Whey and skim milk are sometimes used but without much success. They would be useful for diluting molasses.

6. The Hardeland method of adding crushed sugar-beet or potatoes is still in the experimental stage. The former is probably useful but costly, the value of the latter is unproven.

7. Trials of 'Virtasan' (a mixture of phosphates, ammonium salts, &c.) gave poor results.

8. 'Drowning' with a sugar solution appears to be promising for cheese districts.

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SILAGE IN CANADA

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OWING to the rugged climatic conditions obtaining in Canada, stable-feeding of livestock is necessarily practised in many areas for approximately seven months of the year. This makes summer storage of feed for winter imperative. Storing crops in the form of silage is a very important method of preserving feed, and this is particularly true in areas where corn (maize)[1] will grow satisfactorily. It is becoming increasingly significant where grasses and legumes are grown extensively, and unfavourable weather conditions make it difficult to cure them as hay.

Number of silos.—According to the last census, there are some 45,827 silos used in Canada. Very few, of course, are located in the more specialized grain-growing provinces of Manitoba, Saskatchewan, and Alberta. Excluding these three provinces, approximately 10 per cent. of the farms have silos. The largest proportion of the silos is located in the province of Ontario where corn grows well and is used extensively for silage. Twenty per cent. of the farms in this province have silos, representing a total of 35,716.

Corn for silage.—Corn is the chief crop ensiled. Approximately 400,000 acres of this crop are grown annually which at an average yield of 10 tons per acre produce 4 million tons of feed. There are several reasons why corn predominates as silage. First in importance is the relatively high proportion of carbohydrates, about 17 per cent., to protein, about 2·5 per cent. The presence of this amount of carbohydrates provides adequate material for the lactic-acid bacteria to convert the starches and sugars into lactic acid, which in turn preserves the feed and prevents spoilage. The second factor contributing to the popularity of corn as a silage crop is that of the texture of the cut material. The corn plant when cut to the normal silage length of $\frac{1}{2}$–$\frac{3}{4}$ in., and with a dry-matter content of 20–5 per cent., forms a mass of feed of the right texture and degree of compactness in the silo to exclude sufficient air and provide ideal conditions for the bacteria to function at their best. Thus the corn crop can be converted into highly nutritious silage-feed with relatively little danger of spoilage. A third factor favouring corn production is its high yield in areas where it grows well. In addition, the work of handling corn comes at a different season of the year from other crops, and thus labour is distributed.

There are a number of good reasons, on the other hand, why corn silage is not produced even more extensively in Canada. It is a crop requiring a relatively hot, humid climate for maximum growth. Such conditions prevail in rather limited areas in southern and eastern Ontario and parts of Quebec. In the east, the Maritime Provinces of Prince Edward Island, Nova Scotia, and New Brunswick, which are

[1] Throughout this article 'corn' is synonymous with 'maize'.—*Edit.*

ideal for producing potatoes, hay, and pasture crops, are too cool for satisfactory corn production. On the other hand, the Prairie Provinces of Manitoba, Saskatchewan, and Alberta can grow excellent grain crops, but in the main have too low a rainfall for corn-growing. The coastal and northern regions of British Columbia and northern Ontario and Quebec are rather cool for corn.

In addition to the limitations imposed by climate, corn is a costly crop to grow because of its high labour requirements for cultivating and harvesting. During the 3 years 1944–6, when wages for labour were high, the average cost of growing corn silage at the Dominion Experimental Farm, Ottawa, was $61.88 per acre. The cost per ton of dry matter was $16.63. These costs are high compared with those for alfalfa hay, another forage crop, which for the same period was produced at a cost of $21.24 per acre and $6.49 per ton of dry matter. The yield of dry matter per acre was 3·72 t. in the case of corn and 3·27 t. for alfalfa.

Grass and legume silage.—The picture for grass and legume silage in Canada is not as clear as that for corn. No figures are available in the census or annual statistics regarding the amount of these crops used for silage. Approximately 11½ million acres of hay crops—clover, alfalfa, and grass hay—are grown annually in Canada. Over 7 million acres are produced in the two provinces of Ontario and Quebec where dairy farming predominates. There is no definite information as to how much of this is ensiled, but the amount has been increasing in recent years.

Extensive experiments with various methods of ensiling crops have been conducted at the Central Experimental Farm, Ottawa, since 1924. Twenty-five small experimental silos have been used in studying various crops. Red clover has been successfully ensiled at Branch experimental stations for over 50 years. Some impetus was given to the ensiling of legume and grass silage about 1930 with the introduction of molasses as a preservative. But in spite of this work, which showed that satisfactory feed could be made from these crops as silage, the method has not become as popular as the ensiling of corn.

It is, of course, much more difficult to make a good quality of feed using grasses and legumes than is the case with corn. One of the reasons for this is the relatively higher amount of protein in relation to carbohydrates. Alfalfa on the average contains about 3·7 per cent. protein, which is 50 per cent. more than in corn. The carbohydrates in alfalfa average approximately 8·5 per cent., or 100 per cent. less than in corn. With red clover the difference is not quite as great.

Adding further to the difficulty of producing high-quality feed, with the legumes particularly, is their finer texture and the difficulty of ensiling at the proper moisture-content to produce just the right degree of compaction to exclude most of the air and leave the optimum amount for the proper functioning of lactic-acid bacteria. If the air is completely excluded the anaerobic bacteria and enzymes which work on the proteins break them down into foul-smelling butyric acid, which may render the silage unfit for feed.

A third difficulty with grass and legume silage is the greater losses which occur in the ensilage processes as compared with corn. The

fermentation and heating is more extensive and lasts for longer periods. The average loss in dry matter due to this fermentation in corn has been determined as approximately 15 per cent.; with alfalfa silage losses up to 35 per cent. are not uncommon.

A fourth difficulty with grass and legume silage is that of higher labour and machine costs for handling the heavier green crop as compared with field-cured hay. More than three times as much moisture must be handled in the green crop. This requires more labour and demands sturdily built equipment to prevent breakages.

There are also a number of advantages in making silage of grasses and legumes. The crops can be made into silage under more unfavourable weather conditions than is possible with field-curing for hay. Fermentation losses, although high in silage-making, are not as high as losses due to leaching and bleaching under unfavourable weather conditions in field-curing. Ensiling conserves storage space.

Forage-crop harvesters.—The introduction of forage-crop harvesters in recent years has had, and will continue to have, considerable influence on the production of fodder both as hay and silage. In 1924 the Experimental Farm at Ottawa introduced into Canada from the United States a new type of corn harvester known as the Ronning. This machine cut the standing corn, and fed it immediately through a mechanism which cut it into silage length in the field. The cut material was then transported to the silo into which it was blown with a pneumatic blower. The heavy hand-labour of loading sheaves of corn in the field and unloading them at the silo was thus eliminated. The machine, however, was relatively expensive, costing for harvester and blower approximately $1,500. It has been estimated that such a machine was economical only where about 40 acres of corn are handled annually. Most farmers in Canada grow about 8 acres. Thus only four or five growers of larger acreages found the machine economical enough to purchase.

In 1943 the machinery companies began to develop a forage-crop harvester with a pick-up attachment, which could pick up grass or legume either green or field-cured from the swath or windrow, and cut it into short lengths for storage in the silo or mow. Later, at corn-harvesting time, the pick-up attachment can be removed and a corn-cutting device put on to cut the corn from the row and into silage, similar to the Ronning previously mentioned. Thus a three-way machine is provided which will pick up field-cured hay, green crop for silage, and corn for silage. By placing a canvas on the bottom of the wagon-box with a roller at the end of the box, a motor-driven gear will turn the roller and the canvas will draw the cut material to the back of the box and feed it into the blower.

Thus it is possible to handle any of the three types of crops with no heavy manual labour. This is a great advantage in the present farm-labour shortage. The cost of the machinery is about $1,500 at present high prices. The fact that three crops can be handled during the season, however, cuts down the overhead cost. With 120 t. of material handled per year, the cost per ton, including machine cost, is $2.98, compared with the standard hay-loader method at $1.95 per ton. Although the

harvester method is somewhat more costly, it provides for getting the crop harvested where it is almost impossible to obtain labour at any price. It also allows for handling the grass and clover crop when the weather is too wet for field-curing hay. The latest report of sales shows that 150 of these machines have been sold in Canada to date and there is a demand for many more. It is probable that this development will stimulate a much greater use of both corn and grass silage. A few farmers have already stopped making field-cured hay and feed only half corn silage and half grass and legume silage. It is claimed that the change has made it possible to maintain production with lower requirement for protein supplements and other concentrates; the carotene in the milk has been increased, and the health of the animals has been improved by the use of the succulent feed.

Other silage crops.—Experiments at Ottawa indicate that a wide variety of crops may be ensiled. The following have been made into silage of good quality: alfalfa, alsike, barley, buckwheat, corn, Jerusalem artichoke, kale, millet, oats and peas, red clover, soya beans, sunflowers, sweet clover, and timothy. These crops ensiled individually or in mixtures make good feed. Mixtures of grasses and legumes are usually better than either alone. Molasses at 60 lb. per ton will improve the quality of immature crops high in moisture and in protein-content. It is recommended for pure crops of clover or alfalfa where the molasses can be obtained economically. The use of phosphoric acid or a mixture of hydrochloric acid and sulphuric acid will definitely cut down fermentation losses, and improve the quality of the silage. Their use has never become popular, however, because of their cost, the difficulty of applying, and a reticence on the part of farmers to use acids on animal feeds.

Type of silo.—The most popular silo in Canada is the tower type. Trench silos have been used to a limited extent in the dry area of the Prairie Provinces. In the more humid regions the difficulty of obtaining proper drainage and of removing the silage are factors that have been responsible for their lack of popularity. The tower or upright silo is usually made of concrete, wooden staves, cement, tile or cinder blocks, or of scantling and boards. The most popular size on the average farm is 12–14 ft. in diameter and 30–5 ft. high. The cost of these silos is approximately $500.

With the introduction of modern machines, the making of forage crops into silage for winter feed in Canada appears to be the most economical and efficient means of overcoming unfavourable weather conditions and making nutritious feed of high quality.

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WEST AFRICAN CACAO RESEARCH INSTITUTE: FIELD EXPERIMENTS

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In a note published in *Nature* [1] the history, organization, and financing of the West African Cacao Research Institute have been recorded. It is the purpose of the present article to describe more fully certain aspects of the research programme in connexion with field experiments. When the Institute was inaugurated in 1944 it was fortunate in being able to take over the Gold Coast Agricultural Department's Central Cocoa Research Station at Tafo, which had itself been started only a few years earlier. Although the total area of the station was 164 acres, only 96 acres were considered suitable for cacao experiments, the rest of the area being either swamp or utilized for buildings. The 96 acres comprised, however, a block of cacao, for the most part in bearing, which had been established by local farmers. Descriptions of the Central Cocoa Research Station have been published by Wright [2] and by Greenwood [3] but it may not be out of place to give a brief summary here.

Tafo, some 67 miles inland from Accra, is near the centre of what used to be—before the ravages of swollen-shoot disease—one of the most if not the most productive areas of cacao in the world. Set roughly in a triangle of peneplaned granitic rocks the area is enclosed by hills rising to over 1,000 ft. and comprises about 500 sq. miles. Seen from the air the land appears heavily forested, the cacao, which forms an under story, being scarcely visible. The presence of cacao can be deduced from the numerous small clearings which represent the sites of compounds where the cacao beans are dried.

The climate is undoubtedly kind to cacao, particularly in regard to temperature and humidity, which are constantly high, rarely (and then only for brief periods) falling below 65° F. and 60 per cent. respectively. Rainfall, the annual variation of which has ranged between 84 and 47 in. since 1938, is well distributed, though periods of drought are to be expected during December and January and in August.

Experimental Land

The Old Station.—The 96 acres include 38 acres planted since 1938 with control-pollinated progenies or with clones, the remaining 58 acres being typical of native-planted cacao. The age of these trees is thought to vary from 15 to 30 years; spacing is irregular and there is an irregular density of forest trees of numerous species. This old cacao is divided into quarter-acre blocks on which yields have been recorded since 1938; a considerable number of trees has been individually recorded since that date. Except for supplying vacancies no new planting is envisaged for the old station so that the Institute will always have under close observation cacao typical of the farms in the Gold Coast.

Swollen-shoot disease was discovered on several trees in 1939, and since 1940 regular inspection and cutting out all trees showing symptoms have been effected. In the gaps so formed cacao is being re-established through seed sown at stake according to local practice. The old station now forms a most valuable demonstration of the effectiveness of this method of control. Since 1940 some 3 per cent. of trees have had to be cut out, whereas farms surrounding the station, where no control measures have been adopted, are now for the most part devastated.

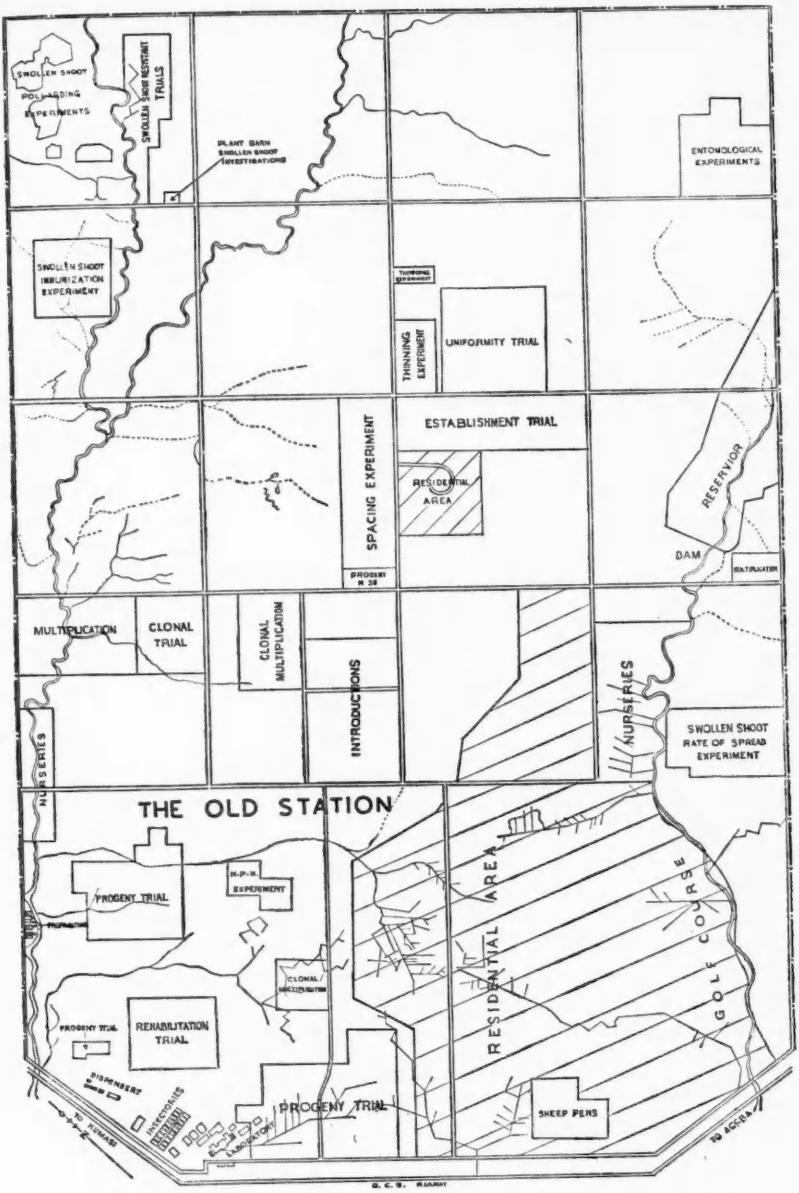
It is the intention of the Institute not to lay down any experiments on the old station that might be expected to lead even to a temporary reduction in yield, but to carry out what are considered the best agronomic practices. These at present include annual removal of dead wood and *Loranthus* (Mistletoe), selective weeding to encourage volunteer forest-tree seedlings, regular harvesting and the removal of diseased pods, the plugging of gaps caused by vacancies with banana, gliricidia, and tree cassava, prior to replanting, and 'painting' the young cacao with D.D.T. emulsion.

The 38 acres of progeny trials in the old station have had a chequered career. Unfortunately these trials were laid down before a soil survey had been undertaken, and several blocks on unsuitable soil have failed to become established. The trials were combined with various shade and establishment experiments which further complicated matters, and until the recent discovery of the use of D.D.T.-painting many of the young plants were killed or severely damaged by capsids. Nevertheless these progeny trials are now coming into bearing and already several selections appear outstanding.

The new acquisition.—One of the first decisions taken by the Institute in 1944 was to increase the area of experimental land. Negotiations, and the payment of £18,000 compensation, resulted in the acquisition of one square mile of land contiguous with the north-east boundary of the Old Station. The new acquisition was entered in 1945, and roads were constructed dividing it into 16 forty-acre blocks. Out of the 640 acres 538 acres had been planted with cacao, the balance being utilized for food farms or coinciding with swamps. When allowances have been made for an extension of the residential area into the new acquisition, for roads, cacao-drying compounds, a water reservoir, and for land unsuited to cacao, there remain some 500 acres that can be used for experiments. To this must be added the 96 acres of the Old Station.

On entering the land, steps were taken to cut out the swollen-shoot diseased trees from the 538 acres of cacao. No less than the equivalent of 172 acres had to be removed. Apart from the high incidence of swollen shoot the condition of the cacao in regard to age, spacing, and overhead shade was similar to that of the old station. It is the policy of the Institute to use the new acquisition for *de novo* field experiments, for introduced varieties of cacao, progeny trials, and multiplication of improved types.

Field experiments on swollen-shoot disease create their own particular problems. The overall objective is to eliminate this disease from West Africa, but the Institute cannot ignore research on possibly tolerant



The West African Cacao Research Institute's Station at Tafo, Gold Coast.

cacao varieties, immunization, rate of spread, and the effect of mild strains of swollen shoot on yield. Much of this work has been carried out in insectaries, but obviously final conclusions can only be drawn under field conditions. All such experiments have, therefore, been relegated to the furthermost extremities of the new acquisition. Reconsideration may have to be given when control measures on farms bordering the Institute's land are put into effect; there might be an understandable source of grievance among the Institute's farming neighbours if the Institute itself deliberately maintained diseased cacao.

Field experiments entailing new planting are laid out according to the soil map, irrespective of whether the sites coincide with existing cacao; if they do the existing cacao is cut down. But apart from this, the existing cacao is maintained as that in the Old Station with one exception. Gaps caused by the removal of diseased trees are allowed to revert to bush and are not replanted. Within the next ten years it is expected that most of the land on the new acquisition will be used for experimental planting.

Soils.—The Institute is indebted to C. F. Charter [4] for a detailed soil map of all its land. The altitude of the station ranges between 755 and 640 ft., and the topography is gently undulating. The higher portions are characterized by sedentary soils with a typical profile which may be briefly described as follows: surface to 1 ft., sandy with appreciable humus; 1 to 2 ft., concretionary layer; 2 to 10 ft., mottled clay overlying decomposing rock. Lower down the slopes the surface sandy layer may reach a depth of 6 ft. or more before the rotten, clayey, decomposing parent rock is encountered. In the small valley-bottoms the soils are grey sand or clay, and are water-logged for considerable periods. The parent rocks underlying the soils on the station are mainly composed of granites, granodiorites, and biotite gneiss.

Experience has shown that the upland sedentary soils of the station are those most suited to cacao. Unfortunately these account for only about half the area. They are, however, typical of very large areas of cacao farms in the Gold Coast and of the majority of cacao farms in Nigeria.

To those accustomed to soils derived from sedimentary rocks, the Institute's land presents a surprising variability. This is due not only to the localized nature of rocks of different composition but also to the consequent depth of soil. Outcrops of rock occur frequently, and within a few yards the depth of soil may vary from a few inches to many feet.

The upland soils have been reserved for standard experiments such as uniformity, spacing, establishment, thinning, and cultivation trials. The soils of the slopes and valley-bottoms, which are even more variable, have been set aside for clonal multiplication and for the genetic examination of progenies. The poorest soils will provide an opportunity to study the effects of drainage and the application of fertilizers—these to be duplicated on good soils.

Experimental difficulties.—Enough has been said of the soils to show that those uniform areas so sought after for field experiments are difficult to find. But, in the search for uniform conditions under which to lay

down new experiments, soil variability is only one undesirable feature. As previously stated the Institute's land supports a numerous forest-tree population. These forest trees—often of immense size—are of many species and their density on the ground varies greatly. For critical experiments on cacao these forest trees and their roots should, theoretically, first be removed. For practical reasons this is quite impossible and the removal of the roots would introduce a new variability in creating uneven soil disturbance. There is little doubt that the cacao would thrive best, under the climatic conditions at Tafo, if these forest trees were left standing to provide shade. It is therefore with reluctance that a compromise between the theoretical best and the practical possible has been reached which involves the clean felling of forest trees in those experiments that are being laid down *de novo*. The compromise permits the felled trees to remain on the experimental plots where they are left to rot. With the destruction of overhead shade it is necessary to establish it anew. Permanent overhead shade is to be provided by volunteer seedlings of those forest trees known not to be harmful to cacao, fortified, where necessary, by planted seedlings. The aim is not to rely on a single species for shade but to obtain a uniform mixture of indigenous species.

A peculiarity with cacao is the need to provide shade from the moment the seed is sown. Temporary shade is given by interplanting other vegetation. In the Institute's standard experiments regularly spaced bananas, gliricidia, and tree cassava are used. In order to ensure that the surface of the soil is never exposed, weed-growth, frequently kept in control, is permitted. The young cacao thus becomes one component of a veritable vegetable salad.

Critical experiments in the past have often been vitiated by the ingress of capsid pests—mainly *Distantiella theobroma* (Dist.). This calamity is now prevented by the routine painting of the young cacao plants with D.D.T. emulsion.

Experimental Technique

Having read so far, the agronomist or statistician whose work has been limited to field experiments on annual crops in temperate climes may well consider that any results which the Institute may obtain will inevitably be inconclusive. Bitter experience in cacao field-experiments has, however, shown that the first essential is to make the cacao grow; it is for this over-riding reason that the conventional experimental procedure has not been closely followed.

The Institute gratefully acknowledges the sound suggestions on the layout of field experiments made by T. N. Hoblyn [5]. In order to overcome the lack of uniformity inherent in the soils and in cultivation practice, experimental plots are replicated more than is usually considered necessary. Each trial is confined as far as possible to the examination of one variable, and complex experiments will be avoided for the present. The standard size of plot is 100 trees planted 8×8 ft. square. This plot-size is almost certainly larger than that required for present experiments but will allow subdivision in the future.

There are many experiments which cannot await the establishment of regularly spaced cacao of uniform age. Fertilizer yield-trials and experiments to control pod disease naturally call for mature bearing cacao. It is necessary therefore to utilize trees established by local farmers, though, as previously stated, these trees are of unknown and variable age and are irregularly spaced under an irregular canopy of forest trees. Owing to staff shortage insufficient work has yet been carried out on the coefficient of variability between trees growing under such conditions, and the optimum plot-size is unknown. Perhaps the most uniform feature is the genetic constitution of the type of cacao grown on native farms in West Africa. Uniformity in this respect—so unlike the seedling cacao of Trinidad and other countries where cultivation is confined to hybrid mixtures—makes some amends for the other variables.

The layout of experiments started this year on native planted cacao has been decided as much by guesswork as by any statistical evidence. A typical experiment on the prevention of pod diseases may be described. Four treatments required testing against the normal practice. It was arbitrarily considered advisable to have 100 trees subject to each treatment. Patches of cacao trees as uniform as could be found were first chosen; within these patches blocks were marked in which there were about 100 trees. Within these blocks five groups of 10 trees were selected, leaving a variable guard-row between each group. The groups of 10 trees were then painted with a distinctive coloured band according to the treatment to be given. These blocks were replicated 10 times. Records are being kept on each group of 10 trees, and apart from any results which may accrue from the treatments, useful statistical information should be obtained.

Work at the Sub-stations

In addition to the main experiment station at Tafo, one sub-station, laid out in 1941, was taken over from the Department of Agriculture, Gold Coast, and four new sub-stations were created. All five are in the Eastern Province of the Gold Coast within 30 miles of Tafo. In Nigeria, the Institute has set up a small entomological sub-station at Owena in Ondo Province to duplicate investigations on the capsid pests of cacao, but no experiments on field agronomy have been undertaken there by the Institute.

The Gold Coast sub-stations were selected in representative areas devastated by swollen-shoot disease, and their main object was to explore the possibility of replanting. With the exception of the former Departmental sub-station at Akwadum, land of the new sub-stations belongs to the original owners, who, disgusted at the loss of their cacao, offered the Institute facilities for experimental replanting in return for the annual payment of nominal rent and all produce from the land. To date both the owners and the Institute are thoroughly satisfied. A subsidiary object of the sub-stations is to provide cacao of uniform age and density on which to carry out field experiments on a scale larger than is practicable at Tafo.

The sub-stations are as follows:

Akwadum	. .	16 acres,	planted	1942
Nankese	. .	18 „	„	1945
Kukua	. .	30 „	„	„
Adonkwanta	.	29 „	„	„
Koransang	. .	20 „	old and young cacao.	

Akwadum was divided into quarter-acre plots and different spacings and different shade-trees are under trial. The attempt to investigate too many variables in one trial has not proved satisfactory; the experience gained at Akwadum confirms what has been learnt from previous field experiments on cacao in West Africa, i.e. that simplicity is the key to success. At the other sub-stations planting distance is 5×5 ft. throughout and as uniform a shade as possible is provided.

At Koransang patches of healthy cacao were still in existence when the Institute took over in 1944. An effort has been made, through regular inspection and cutting out swollen-shoot diseased trees, to maintain this mature cacao, but only one-third of the apparently healthy trees found in 1944 remains. Cutting out has merely delayed the inevitable destruction of all. The inefficacy of the control on this sub-station is undoubtedly due to the small area over which it is practised and to the huge reservoir of disease on contiguous farms. Where the trees had died or been cut out cacao has been planted 5×5 ft.

The outstanding fact on all these sub-stations is the great patchiness in the growth of the young cacao. Areas occur at each where luxuriant growth merges into a fair stand, which in turn leads to patches where, even after repeated attempts, the cacao has failed to become established. Detailed soil surveys have shown this variation to be due to the occurrence of different soils. The information gained has been of material assistance in the classification of soils good and bad for cacao. Even on the good soils growth is in places irregular, and it has been found that where poor growth occurs on soils known to be good for cacao the reason is to be found in the previous treatment of the land. Farms devastated by swollen shoot are either allowed to revert to bush or are farmed for food. If farmed with such crops as maize, okras, or chillies, which require clean weeding, the soil is in poor condition for the establishment of cacao. After the removal of a clean-weeded crop the first vegetation to occur is grass; experience on the sub-stations has shown that conditions suitable for grass are unsuitable for cacao.

At Adonkwanta and Kukua the sub-stations are divided into two; on one half no disease or capsid control is practised, whilst on the other half young plants showing swollen-shoot symptoms are rogued and D.D.T. emulsion is regularly applied. It is noteworthy that although all the sub-stations are surrounded by farms devastated by swollen shoot, the incidence of this disease on the young cacao amounts to less than 0·03 per cent. The sub-stations provide encouraging demonstration of the practicability of replanting.

Experiments in conjunction with Agricultural Departments

Both in the Gold Coast and in Nigeria close co-operation with the Agricultural Departments is maintained. In other parts of the tropical Commonwealth it is usual for the results of research, and indeed collaboration in research, to be followed closely by the managers of estates. There are no cacao estates of any importance in British West Africa, and the Departments of Agriculture have to carry the whole burden of making sure that the practical application of the Institute's findings are given effect by the peasant farmer. There must be an unbroken chain leading from the research work, often of a somewhat fundamental nature and carried out by the Institute's specialists, to the cacao farm owned by an illiterate farmer. It is therefore of supreme importance that not only should the Agricultural Departments be well acquainted with the experiments conducted on the Institute's land but also that the Institute should give every assistance to Departmental field trials.

An example of such collaboration may be given. In order to find out whether the application of nitrogenous fertilizers would facilitate the rapid establishment of seedling cacao in areas where swollen-shoot diseased trees had been cut out, the Gold Coast Department and the Institute collaborated in laying down trials. The site of the experiment, statistical layout, and rates of application were determined by the Institute's staff, whilst the Department took responsibility for the field work. Similarly, field investigations on the rate of spread and effect on yield of cacao viruses of the Gold Coast Western Province are being carried out there with the close co-operation of the Agricultural Department. It is hoped that many more experiments will result from this method of combined operations.

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THE TYPE OF LAND AVAILABLE FOR EXPERIMENTS

The forest trees, whether felled or left standing, introduce a factor of variability which is rarely encountered in field experiments in temperate climates

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